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अर्धचालक युक्तियाँ — विविक्त युक्तियाँ एवं समाकलित परिपथ

भाग 4 माइक्रोवेव युक्तियाँ

Indian Standard

SEMICONDUCTOR DEVICES — DISCRETE DEVICES AND INTEGRATED CIRCUITS

PART 4 MICROWAVE DEVICES

ICS 31.080,31.080.30,31.080.99

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Price Group 19

Semiconductor Devices and Integrated Circuits Sectional Committee, LTD 10

NATIONAL FOREWORD

This Indian Standard (Part 4) which is identical with IEC 60747-4 (2001) 'Semiconductor devices — Discrete devices — Part 4 : Microwave devices' [incorporating Amendment 1 (1993) and Amendment 2 (1999)] issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendations of the Semiconductor Devices and Integrated Circuits Sectional Committee and approval of the Electronics and Telecommunication Division Council.

This standard covers the terminology, letter symbols, essential ratings and characteristics, methods of measurements, and acceptance and reliability criteria for microwave diodes and transistors.

The object of this series of standards is to specify adequately the properties of the device for the intended application and to facilitate comparison and choice between similar products.

Hitherto, IS 3700, IS 3715 and IS 4400 series, based on IEC 147 series of standards, covered essential ratings and characteristics, letter symbols and methods of measurements of semiconductor devices respectively. However, IEC 147 series has been superseded by IEC 747 series. The present series of standards has been brought out to consolidate the provisions of IS 3700, IS 3715 and IS 4400 series and align it with the latest version of IEC 747 series.

This Indian Standard (Part 4) shall supersede the following Indian Standards:

IS 3700 (Part 9) : 1972 Essential ratings and characteristics of semiconductor devices: Part 9 Variable capacitance diodes,
IS 4400(Part 9/Sec 1):1974 Methods of measurement on semiconductor devices: Part 9 Variable capacitance diodes, Section 1 For operating frequencies below 300 MHz, and
IS 4400(Part 9/Sec 2):1974 Methods of measurement on semiconductor devices: Part 9 Variable capacitance diodes, Section 2 For operating frequencies above 6 GHz.

The text of IEC Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.
b) Comma (,) has been used as a decimal marker, while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

Only the English language text in the International Standard has been retained while adopting it in this standard.

CROSS REFERENCE

In this adopted standard, reference appears to the following International Standard for which Indian Standard also exists. The corresponding Indian Standard which is to be substituted in its place is given below along with its degree of equivalence:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60747-1 (1983) Semiconductor devices — Discrete devices and integrated circuits — Part 1 : General	IS 14901 (Part 1) : 2001 Semiconductor devices — Discrete devices and integrated circuits : Part 1 General	Identical

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Indian Standard

SEMICONDUCTOR DEVICES — DISCRETE DEVICES AND INTEGRATED CIRCUITS

PART 4 MICROWAVE DEVICES

CHAPTER I: GENERAL

1 Introductory note

As a rule, it will be necessary to use IEC 60747-1 together with the present publication. In IEC 60747-1 the user will find all basic information on:

- terminology;
- fetter symbols;
- essential ratings and characteristics;
- measuring methods;
- acceptance and reliability.

The sequence of the different chapters in the present publication is in accordance with 2.1, chapter III, IEC 60747-1.

2 Scope

The present publication gives standards for the following categories of discrete devices:

- Variable capacitance diodes and snap-off diodes (for tuning, up-converter or harmonic multiplication, switching, limiting, phased shift, parametric amplification...)
- Mixer diodes and detector diodes
- Avalanche diodes (for direct harmonic generation, amplification...)
- Gunn diodes (for direct harmonic generation...)
- Bipolar transistors (for amplification, oscillation...)
- Field-effect transistors (for amplification, oscillation...).

3 Letter symbols

Mostly, existing letter symbols are added to the terms in titles. When several distinct forms exist, the most commonly used form is given.

CHAPTER II: VARIABLE CAPACITANCE, SNAP-OFF DIODES AND FAST-SWITCHING SCHOTTKY DIODES

Section 1: Variable capacitance diodes

1 General

The provisions of this part deal with diodes (excluding snap-off diodes) in which the variable capacitance effect is used; they cover four applications: tuning, harmonic multiplication, switching (including limiting), parametric amplification.

The devices for these applications are defined as follows:

Diodes for tuning

Diodes which are used to vary the frequency of a tuned circuit.

These diodes are usually characterized a frequency of resonance much higher than the frequency of use and have a known capacitance/voltage relationship.

Diodes for harmonic multiplication

These diodes must have a non-linear capacitance/voltage relationship at the frequency of operation and a high ratio of cut-off frequency to operating frequency.

Diodes for switching (including limiting)

These diodes exhibit a fast transition from a high impedance state to a low impedance state and vice versa and can be used to modulate or control the power level in microwave systems.

Diodes for parametric amplification

These diodes are intended to handle small amplitude signals and are most often used in low-noise amplifiers.

2 Terminology and letter symbols

See subclause 3.3.

3 Essential ratings and characteristics

3.1 General

3.1.1 Rating conditions

Variable capacitance diodes may be specified either as ambient rated or case rated devices or, where appropriate, as both.

The ratings listed in 3.2 should be stated at the following temperatures:

Ambient-rated devices

At an ambient temperature of 25 °C and at one higher temperature chosen from the list given in IEC 60747-1.

Case-rated devices

At a reference point temperature of 25 °C and at another reference point temperature chosen from the list given in IEC 60747-1.

3.1.2 Application categories

The essential ratings and characteristics to be stated for each category of diode are marked with a + sign in the following table:

- column 1: tuning applications;
- column 2: harmonic multiplication applications;
- column 3: switching (including limiting) applications;
- column 4: parametric amplification applications.

3.2 Ratings (limiting values)

The following ratings should be stated:

3.2.1 Temperatures

	Categories			
	1	2	3	4
Range of operating temperatures	+	+	+	+
Range of storage temperatures	+	+	+	+

3.2.2 Voltages and currents

	1	2	3	4
Maximum peak reverse voltage	+	+	+	+
Maximum mean forward current, where appropriate		+	+	+
Maximum peak forward current, where appropriate		+	+	+

3.2.3 Power dissipation

	1	2	3	4
Maximum dissipation, under stated conditions, over the operating temperature range	+	+	+	+

3.3 Electrical characteristics

Unless otherwise specified, the following characteristics should be given at 25 °C (see figure 1)

3.3.1 Stray capacitance (C_p)

	1	2	3	4
Typical value under specified conditions	+	+	+	+

3.3.2 Series inductance (L_s)

	1	2	3	4
Typical value and, where appropriate, maximum value under specified conditions	+	+	+	+

	Categories			
	1	2	3	4
3.3.3 Terminal capacitance (C_{tot})				
a) Minimum and maximum values, at a specified bias voltage and at a specified frequency (note 1)	+	+	+	+
b) Typical curve showing the relationship between terminal capacitance and bias voltage	+	+	+	+
3.3.4 Junction capacitance (C_j)				
Minimum and maximum values at a specified bias voltage (notes 1 and 2). When the order of magnitude of C_p is the same as that of the terminal capacitance C_{tot}, a typical value should be given for C_j instead	+	+	+	+
3.3.5 Effective quality factor (Q)				
Minimum values at two or more specified frequencies under specified bias conditions (note 3)	+			
3.3.6 Cut-off frequency				
Minimum value under specified conditions (notes 3 and 4)		+	+	+
3.3.7 Series resistance (r_s)				
Maximum and/or typical values under specified conditions (note 3)	+	+	+	+
3.3.8 Reverse current				
Maximum value at a specified reverse voltage	+	+	+	+
3.3.9 Thermal resistance				
Maximum value between junction and ambient, or between the junction and a specified reference point	+	+	+	
3.3.10 Switching time				
Typical value under specified conditions			+	
3.3.11 Stored charge or minority carrier life time				
Typical value, for either stored charge under specified conditions including bias, or minority carrier life time under specified conditions		+	+	
3.3.12 Transition time				
Typical value, under specified conditions, together with a specified measurement circuit		+		

NOTE See definition in section 2.

NOTE 1 For categories 1, 2 and 3, the specified bias voltage should be –6 V and for category 4, the specified bias voltage should be 0 V.

NOTE 2 The relationship between the junction capacitance and bias voltage should be represented either by a typical curve or by a mathematical form. The mathematical form should be as follows:

$$C_j = K (V + \phi)^{\gamma}$$

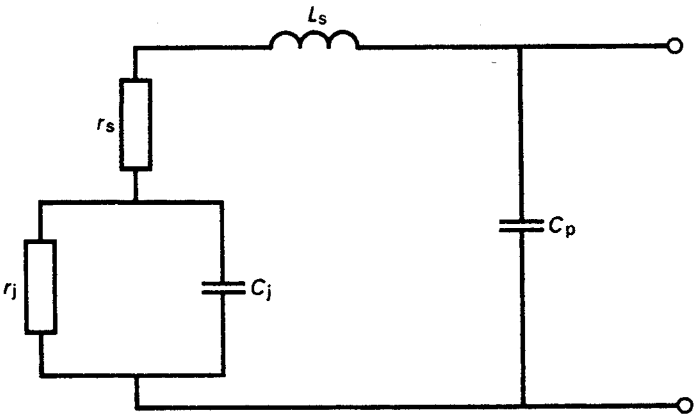
where V is the magnitude of the applied reverse voltage and K, ϕ and γ are three constants. The manufacturer should specify the typical values for K, ϕ and γ.

NOTE 3 If the Q value and the series resistance are not specified for category 1, then the cut-off frequency must be specified.

NOTE 4 The cut-off frequency f_c is defined as:

$$f_c = \frac{1}{2\pi \, r_s \, C_j}$$

where r_s is the series resistance and C_j is the capacitance of the junction measured at a specified bias point r_s is determined by the equivalent circuit shown in figure 1 below; its value depends on the measuring method used and on the bias voltage.



C_j = junction capacitance
r_s = series resistance
r_j = low frequency resistance of the junction.
In general, r_j is sufficiently high to be neglected
C_p = stray capacitance
L_s = series inductance

Figure 1 – Equivalent circuit

3.4 Application data

For harmonic multiplication applications, the *efficiency* should be stated.

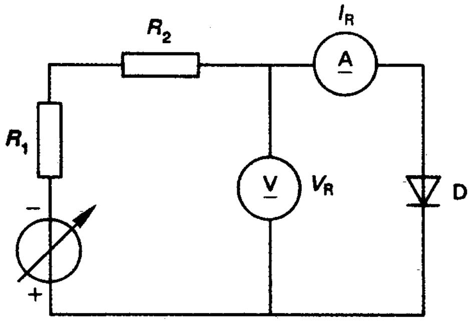
4 Measurement methods

4.1 Reverse current I_R

a) *Purpose*

To measure the reverse current of a diode under specified reverse voltage.

b) *Circuit diagram*



D = diode being measured

Figure 2

c) *Circuit description and requirements*

R_1 is a calibrated resistor (pulse measurement only).

R_2 is a protective resistor.

If a pulse measurement is required, the variable voltage generator is replaced by a voltage pulse generator, the voltmeter is replaced by a peak-reading instrument and the ammeter is replaced by a peak-reading voltmeter across the calibrated resistor R_1.

d) *Measurement procedure*

The temperature is set to the specified value.

The variable voltage generator is adjusted to obtain the specified value of reverse voltage V_R across the diode.

The reverse current I_R is read from the ammeter A.

e) *Specified conditions*

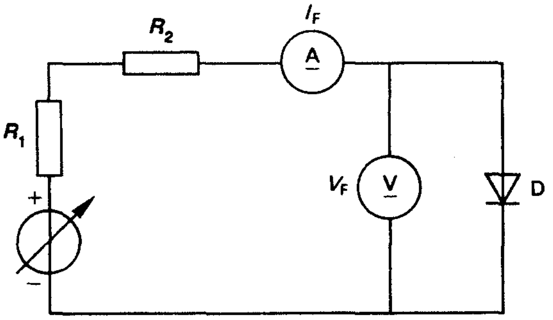
- Ambient, case or reference-point temperature (t_{amb}, t_{case}, t_{ref}).
- Reverse voltage (V_R).
- Pulse width and duty cycle, where applicable.

4.2 Forward voltage V_F

a) *Purpose*

To measure the forward voltage across a signal or switching diode under specified conditions.

b) *Circuit diagram*



D = diode being measured

Figure 3

c) *Circuit description and requirements*

R_1 is a calibrated resistor (pulse measurement only).

R_2 is a high value resistor.

If a pulse measurement is required, the variable voltage generator is replaced by a voltage pulse generator, the voltmeter is replaced by a peak-reading instrument and the ammeter is replaced by a peak-reading voltmeter across the calibrated resistor R_1.

d) *Measurement procedure*

The temperature is set to the specified value.

The variable voltage generator is adjusted to obtain the specified value of forward current I_F.

The forward voltage V_F is read from the voltmeter V.

e) *Specified conditions*

- Ambient or case temperature (t_{amb}, t_{case}).
- Forward current (I_F).
- Pulse width and duty cycle, where applicable.

4.3 Capacitance C_{tot}

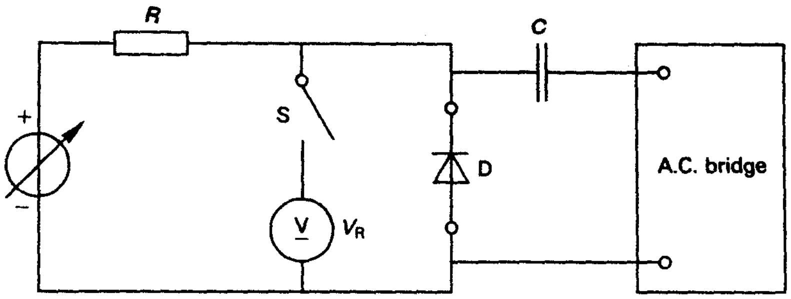
The measurement of total capacitance ($C_{tot} = C_j + C_p$) should be made at a sufficiently low frequency (below microwave frequencies) so that the effects of the lead inductance may be neglected. Under these conditions, the measured value of terminal capacitance is independent of frequency.

The total capacitance at a given bias condition is obtained by the method stated hereafter.

a) *Purpose*

To measure the total capacitance of a diode under specified conditions.

b) *Circuit diagram*



D = diode being measured

Figure 4

c) *Circuit description and requirements*

The conductance of resistor *R* should be low compared with the admittance of the diode being measured.

The capacitor C must be able to withstand the reverse bias voltage of the diode and should present a short circuit at the frequency of measurement.

d) *Precautions to be observed*

The bridge must be able to withstand the reverse bias voltage of the diode without affecting the accuracy of the measurement. If the measured capacitance is very small, the mounting conditions will affect the accuracy of the results and they should be specified.

e) *Measurement procedure*

The temperature is set to the specified value.

The voltage across the diode is adjusted to the specified value V_R. Then the voltmeter V is taken out of the circuit and the capacitance of the diode being measured is determined using the a.c. bridge by subtracting the value without the diode in its mounting from the value with the diode in its mounting.

f) *Specified conditions*

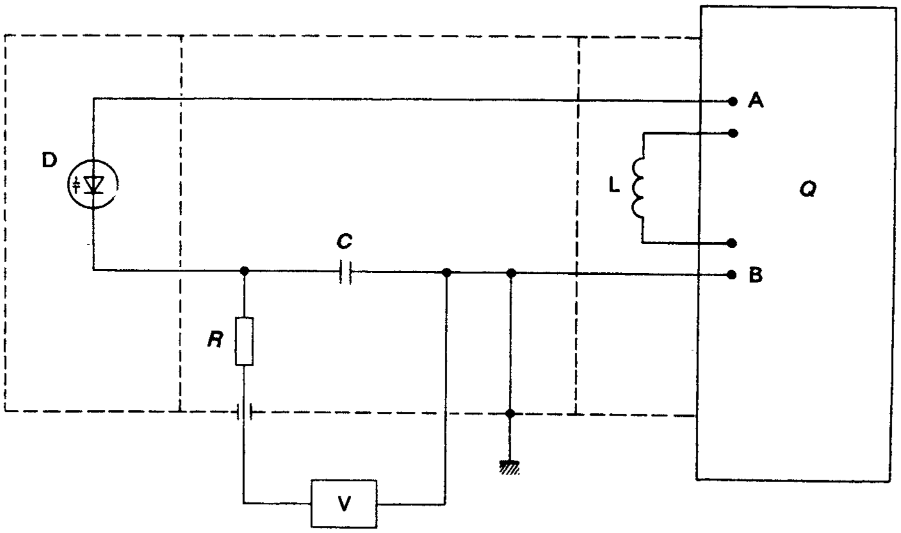
Ambient or case temperature (t_{amb}, t_{case}).

- Reverse voltage (V_R).
- Measurement frequency, if different from 1 MHz.
- Mounting conditions of the diode, if necessary.

NOTE The variation of total capacitance with bias voltage may be found by measurements as described above, made at a number of bias points.

4.4 Effective quality factor *Q*

The effective quality factor *Q* of a variable capacitance diode can be measured using a "Q-meter" or an impedance bridge (see figure 5).



D = diode being measured
V = voltage source
Q = Q-meter

Figure 5 – Basic circuit for the measurement of effective quality factor

Description

1) The voltage source should present a high impedance at the frequency of measurement compared to that of the capacitor *C*; this is obtained by means of series resistor *R*.
2) *C* is a decoupling capacitor having a low impedance at the frequency of measurement.
3) L is an inductor chosen to resonate with the parallel circuit capacitor at the frequency of measurement.
4) It is assumed that there is a low resistance path through the Q-meter between points A and B.

The basic circuit of such a meter consists of a signal generator of negligible output impedance driving a high Q inductance in series with a high-quality variable capacitance. The factor Q of this circuit can be measured at a given frequency by tuning the variable capacitance for resonance.

Q is given by the ratio of the voltage across the capacitance to the voltage supplied by the generator. In order to measure the factor Q of a variable capacitance diode, it must be connected in parallel with the variable capacitance in the *Q*-meter. DC isolating components must be used so that the desired bias voltage may be applied to the diode being measured, but the biasing circuit must remain connected to the *Q*-meter throughout the measurement.

Four measurements are made: *Q* and C_1, the factor *Q* of the circuit and the magnitude of the variable capacitance with the diode not in circuit; and Q_2 and C_2, the factor Q of the circuit and the value of the variable capacitance for resonance at the same frequency with the diode connected to the circuit.

The factor Q of the diode is then calculated using the expression:

$$Q = \left(\frac{Q_1\,Q_2}{Q_1 - Q_2}\right) \quad \left(\frac{C_1 - C_2}{C_1}\right)$$

Two precautions are necessary:

1) The measurement must be made at a frequency at which the reactance of the self-inductance of the diode is negligible compared with the reactance of the capacitor.
2) The magnitude of the signal applied to the variable capacitance diode must be kept relatively small so that only a small excursion is made over the non-linear capacitance characteristic. The result must be independent of the signal level.

NOTE

$$Q = \frac{1}{2\pi f \bullet C_j \bullet r_s} = \frac{f_c}{f}$$

Since $C_p \leq C_j$ for these diodes, C_t and C_j can be used interchangeably in this section.

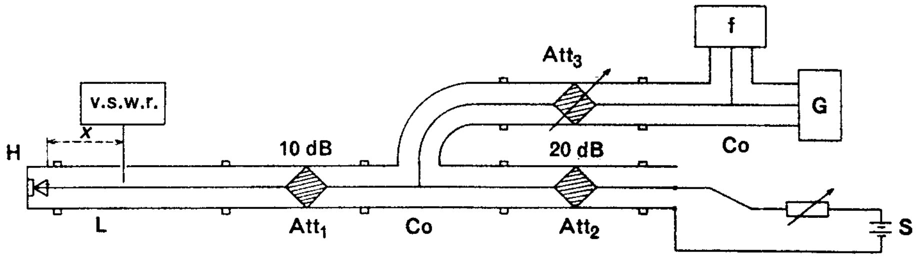
4.5 Series resistance r_s

The effective value of series resistance r_s can be deduced from the values of C_j and f using the formula given in 4.4.

4.6 Series inductance L_s

Measurements should be conducted in the frequency region where the effect of stray capacitance C_p relative to the terminal impedance of the diode can be neglected.

The diode is inserted in the measuring head as shown in figure 6 which is set on the tip of the inner conductor of the coaxial slotted line.



v.s.w.r. = voltage standing wave ratio meter
x = distance
H = diode head
L = slotted line
Att = attenuator
Co = coupler
G = microwave generator
S = bias supply
f = frequency meter

Figure 6 – Basic circuit for the measurement of series inductance

Measurements are as follows:

First, determine position x_m where the standing wave voltage is minimum as measured at a bias voltage in the forward region where the terminal capacitance becomes independent of the change of bias voltage. This bias voltage should be sufficiently high so that an increase of this voltage would not affect the result of the measurement. (This condition may be satisfied when about 5 mA forward current flows.)

Next, without any break in the impedance of the line, a metal block is inserted in the measuring head in place of the diode. This is done in order to provide a short-circuit at the reference plane position which is defined and should be specified by the manufacturer of the diode. In this condition, position x_s nearest to x_m and larger than x_m is found where the standing wave voltage is minimum.

The reactance of the diode is obtained by the following equation:

$$X = Z_o \tan \frac{2\pi(x_s - x_m)}{\lambda}$$

where

Z_o = characteristic impedance of the coaxial line

λ = wavelength of the measuring frequency

The series inductance L_s can be obtained by use of the following equation:

$$L_s = \frac{X}{2\pi f}$$

NOTE The structure of some devices may prevent this method of measurement from giving correct results. In this case, a value for the inductance will have to be given by the manufacturer.

4.7 Thermal resistance R_{th}

4.7.1 Purpose

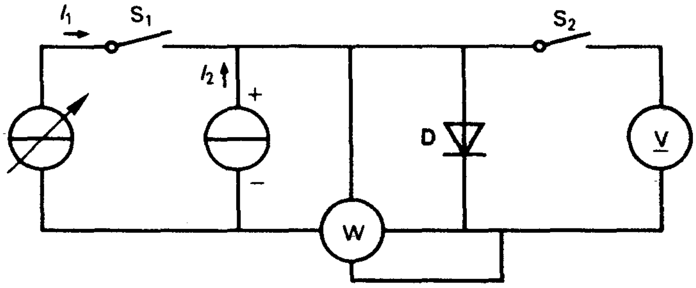
To measure the thermal resistance between the junction and a reference point (preferably at the case) of the device being measured.

4.7.2 Principle of the method

The temperatures T_1 and T_2 of the reference point of the device are measured for two different power dissipations P_1 and P_2 and cooling conditions causing the same junction temperature. The forward voltage at a reference current is used to verify that the same junction temperature has been reached.

$$R_{th} = \frac{T_1 - T_2}{P_2 - P_1}$$

4.7.3 Basic circuit diagram



D = device being measured

Figure 7

4.7.4 Circuit description and requirements

I_1 = load current generating the power loss P in the junction, either a d.c. current or an a.c. current

I_2 = reference d.c. current monitored when the load current I_1, is interrupted periodically for short time gaps

W = wattmeter to indicate the power loss P in the junction caused by the load current I_1; for the a.c. method, W measures the average power dissipated in the device being measured

S_1 = electronic switch to interrupt periodically the load current I_1; for the d.c. method, switch S_1 is not mandatory

S_2 = electronic switch, which is closed when the load current I_1, is interrupted

V = null-method voltmeter

4.7.5 Precautions to be observed

Voltage transients occur due to excess charge carriers when switching from the load current I_1, to the reference current I_2. Additional voltage transients occur if the case of the device under test contains ferromagnetic material. The switch S_2 should not be closed before these transients have disappeared.

NOTE The load current I_1 defined in 4.7.4 may be zero, in which case the power loss P_1 is also zero and the virtual junction temperature is the same as the reference-point temperature T_1.

4.7.6 Measurement procedure

The device being measured is clamped onto a heat sink maintained at a fixed temperature. A thermocouple is fixed at the reference point to measure the temperature of the device being measured. The measurement is done in two steps.

a) The heat sink is maintained at an elevated temperature. A low load current I_1, is applied causing the power loss P_1, in the junction. After reaching thermal equilibrium, the null-method voltmeter V is adjusted for zero balance.

   The reference-point temperature T_1 is recorded.

b) The heat sink is maintained at a lower temperature. The load current I_1, is raised until the power loss P_2 warms up the junction to the same temperature as in the preceding step. This is indicated by zero balance of the null-method voltmeter V.

The reference-point temperature T_2 of the case is recorded.

The thermal resistance R_{th} is calculated using the expression:

$$R_{th} = \frac{T_1 - T_2}{P_2 - P_1}$$

4.8 Transient thermal impedance Z_{th}

4.8.1 Purpose

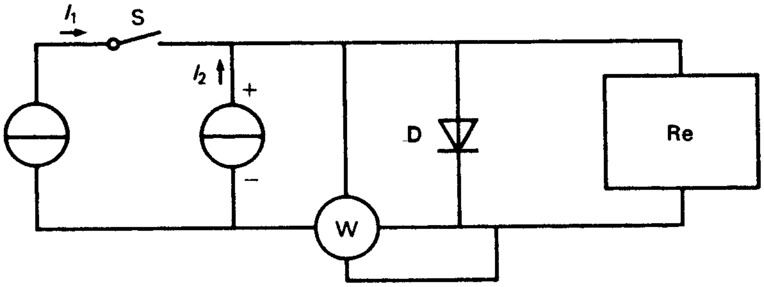
To measure the transient thermal impedance between the junction and a reference point (preferably at the case) of the device being measured.

4.8.2 Principle of the method

After applying the heating current and waiting until thermal equilibrium is reached, the power dissipated in the device is recorded. The heating current is then interrupted and the forward voltage at the reference current together with the reference-point temperature are recorded as a function of time.

The virtual junction temperature as a function of time is then calculated by means of the calibration curve obtained for the same reference current.

4.8.3 Basic circuit diagram



D = device being measured

Figure 8

4.8.4 Circuit description and requirements

I_1 = load current generating the power loss P in the junction

I_2 = reference d.c. current

S = switch to interrupt the load current I_1

W = wattmeter to indicate the power loss P in the junction caused by the load current I_1

Re= recording equipment, e.g. an oscillograph, to record the time variation of the forward voltage caused by I_2

4.8.5 Measurement procedure

1) A calibration curve is prepared by measuring the on-state or forward voltage generated by the reference current I_2 as a function of the virtual junction temperature by varying the device temperature externally e.g. by means of an oil bath.
2) The device being measured is clamped onto a heat sink maintained at a fixed temperature. A thermocouple is fixed at the reference point to measure the reference point temperature T_c of the device being measured. The heating current I_1 is applied generating the power loss P in the device being measured until thermal equilibrium is reached.
3) The heating current I_1, is interrupted by opening the switch S. The forward voltage generated by the reference current I_2 is recorded as a function of the cooling time by the recording equipment Re. The reference point temperature is recorded during this time.
4) The curve of the recorded forward voltage is converted to the virtual junction temperature T_{vj} by means of the calibration curve. The transient thermal impedance $Z_{(th)t}$ is calculated using the expression:

$$Z_{(th)t} = \frac{\left[T_{vj}(0) - T_c(0)\right] - \left[T_{vj}(t) - T_c(t)\right]}{P}$$

where

$T_{vj}(0)$ and $T_c(0)$ = temperatures at the time $t = 0$ when opening switch S

$T_{vj}(t)$ and $T_c(t)$ = temperatures at the time t

4.9 Case of varactor diodes

The following methods of measurement are recommended for use as appropriate to the intended conditions of operation and structure of the type of diode to be measured.

In the case of the measurement of the effective factor Q of the diode, it is recommended that, when a value of Q is quoted, the particular method of measurement used to obtain that value should be stated. This is necessary because it is possible to obtain different values of Q for a given diode when using the two given methods.

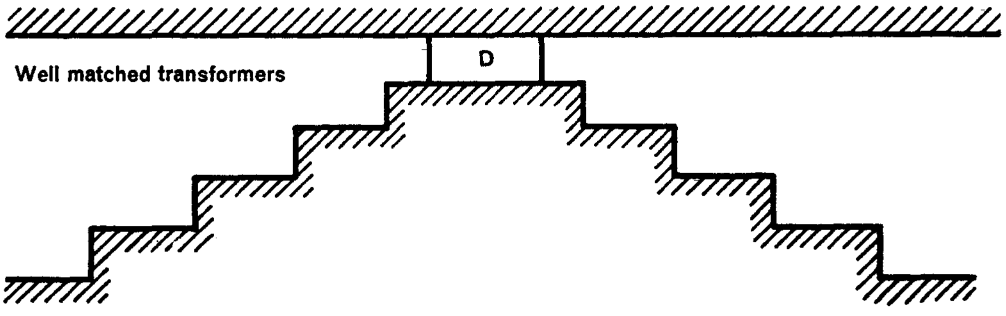
4.9.1 Transmission line measurements

These measurements are suitable for evaluating the main properties of microwave diodes which may be used in a wide range of applications, particularly those diodes which are unencapsulated, or those diodes whose package shunt capacitance has a reactance value larger than the value of diode series resistance at the series resonant frequency.

4.9.1.1 Theory

Observation is made of the effect on the transmission characteristics of any non-radiating transmission system by the introduction of a shunt impedance, in this case a diode.

The diode is mounted in shunt with the transmission line so that the mounting arrangement provides a minimum of excess reactance; for example, when using a waveguide transmission system, the diode is fitted as given in figure 9.



D = diode being measured

Figure 9 – Waveguide mounting

Measurements of transmission loss introduced by the diode in the region of the series resonant frequency enable the elements of the diode equivalent circuit to be evaluated and also permit the capacitance law as a function of bias to be determined.

The equivalent circuit of the mounted diode is shown in figure 10.

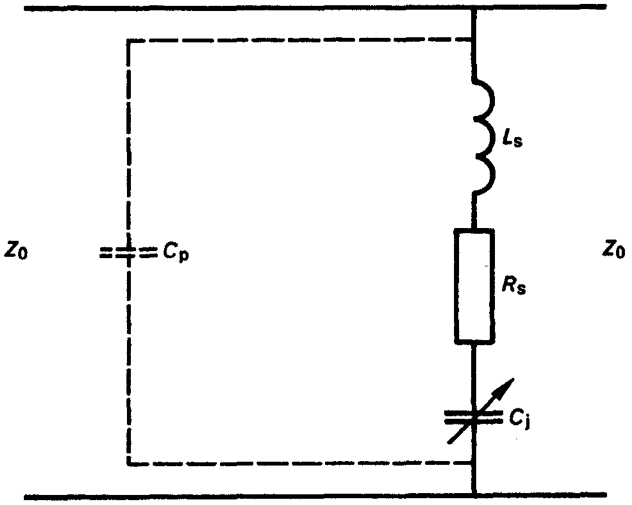


Figure 10 – Equivalent circuit of mounted diode

where

Z_0 = characteristic impedance of transmission line
C_p = package capacitance
L_s = series inductance
R_s = series resistance
C_j = junction capacitance

Near series resonance, the effect of the package capacitance (C_p) is negligible and may be ignored.

Four measurements, namely:

a) transmission loss at the series resonant frequency at zero bias;

b) the bandwidth of the transmission characteristic;

c) the value of the series resonant frequency;

d) the variation of the series resonant frequency with bias;

enable the four unknown quantities:

1) Series resistance (R_s);

2) Junction capacitance (C_j);

3) Series inductance (L_s);

4) Variation of junction capacitance with bias to be determined.

4.9.1.2 Circuit diagram

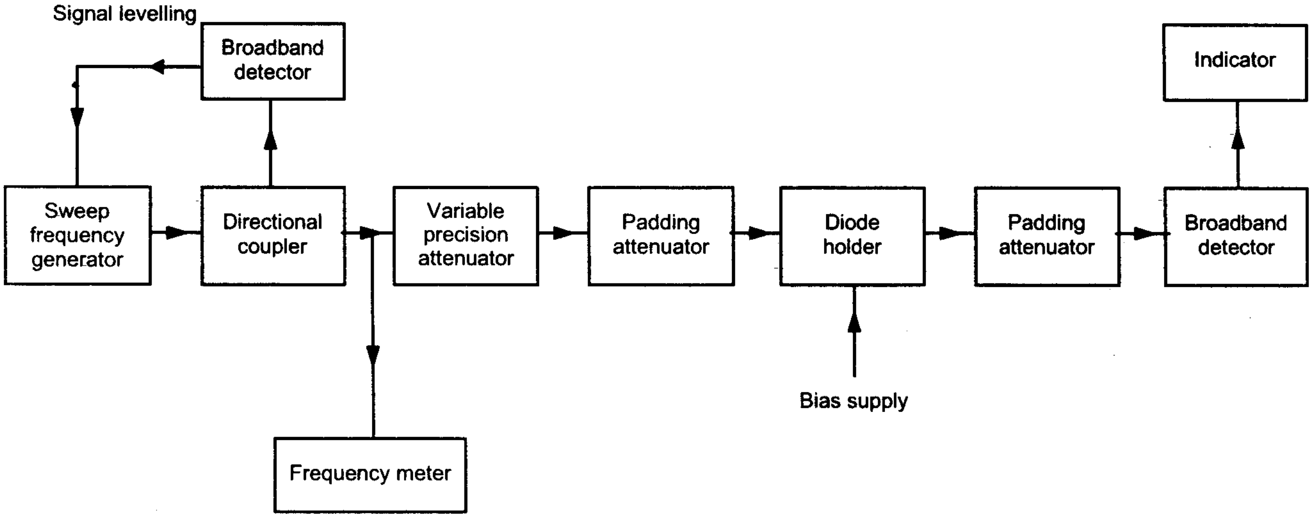


Figure 11 – Block diagram of transmission loss measurement circuit

4.9.1.3 Circuit description and requirements

The test equipment should be assembled using good microwave transmission line engineering techniques. All components, such as directional couplers, frequency measuring apparatus, attenuators and detectors, should be checked to ensure proper matching and operation over the required frequency and power test conditions.

The components of the system should be sufficiently broadband to ensure that only negligible variations or errors over the band of frequencies used for the measurement are introduced.

The RF signal generator should be capable of stable operation at a signal level equivalent to the normal small-signal conditions of the diode.

The diode holder should conform with the specified mount details.

A typical arrangement comprises a tapered mount with a choke on one face to enable bias to be applied. The tapered mount usually is a requisite feature to ensure that only the diode characteristics are being measured. In this way, the complication of using inductive posts for mounting the diode is avoided (see figure 9).

4.9.1.4 Measurement procedure

The diode is inserted into the specified holder which is connected in a transmission system equivalent to that shown in figure 11.

4.9.1.4.1 Series resonant frequency

The series resonant frequency may easily be obtained by operating the diode at the required bias voltage and observing the indicated transmitted power, in front of and behind the diode, as the frequency is swept over a suitable frequency range. The series resonant frequency is indicated by the point of minimum transmitted RF power. The incident RF power level on the diode shall be kept constant during the sweep.

4.9.1.4.2 Transmission loss (*T*)

The transmitted signal level at resonance with zero bias (or any other required value) applied to the diode is recorded. The diode is then removed from the holder and the precision attenuator adjusted to give the same indicated transmitted signal level as the one recorded initially. The change in the attenuator setting then gives the transmission loss (*T*) at resonance. It is essential that the incident RF power level on the diode shall be kept constant during this measurement.

Alternatively, the transmission loss introduced by the diode at the series resonant frequency may be obtained by firstly observing the power level incident on the matched detector at a frequency remote from the resonant frequency. The frequency is then changed to the resonant value and the precision attenuator adjusted to return the indicated power level to the same value as that obtained when the frequency was remote from resonant value. The change in attenuator reading will provide the transmission factor (*T*) (see figure 12).

4.9.1.4.3 Series resistance

If the frequency of measurement chosen is equal to the series resonant frequency (f_s) given by:

$$f_s = \frac{1}{2\pi\sqrt{L_s\,C_j}} \tag{1}$$

where

L_s = series inductance

C_j = effective capacitance of the PN junction having a required applied bias voltage

the loss in a transmission may be measured as in 4.9.1.4.2 and the effective shunt resistance derived from:

$$R_s = \frac{Z_0}{2\sqrt{T}-1} \tag{2}$$

where

Z_0 = characteristic impedance of the transmission line in the vicinity of the loss element. In the case of a waveguide mount, the power/voltage definition should be used

T' = ratio of available power incident on the diode being measured to that transmitted past the diode

The variation of R_s with bias may be obtained by the adjustment of the measuring frequency to the corresponding series resonant value obtained for each bias value used and measuring the transmission factor (T) in each case.

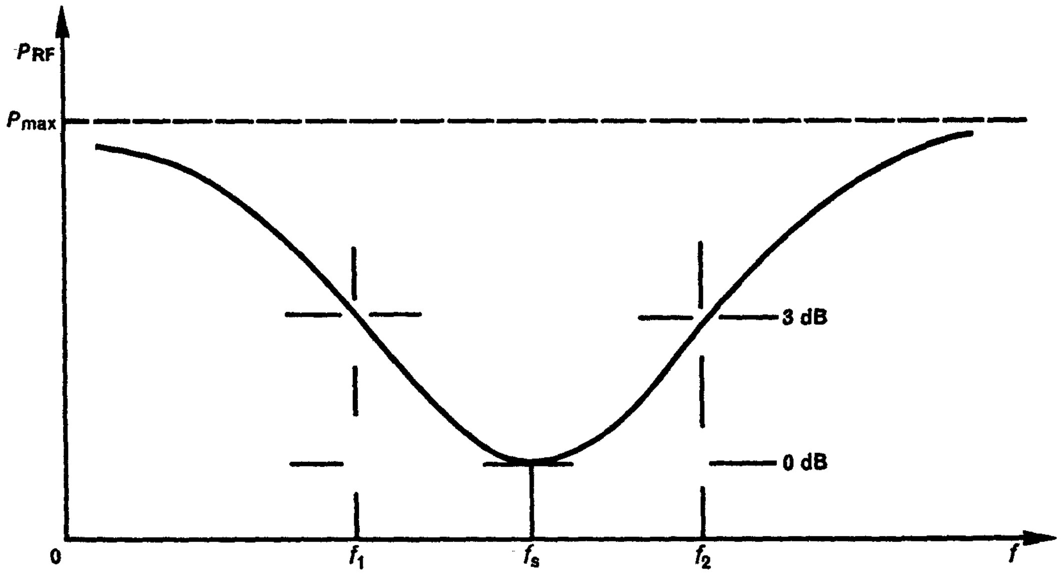
A measure of the change in the effective Q value with bias may also be obtained.

4.9.1.4.4 Effective *Q* value

a) *First method*

The effective Q value at a given bias voltage may be obtained by varying the measuring frequency to values on either side of the series resonant frequency and observing the value of those frequencies which cause the power transmitted to be twice the one obtained at the resonant frequency (see figure 12). If the frequencies at which this is achieved are f_1 and f_2, then:

$$Q = \frac{f_s}{|f_1 - f_2|}$$



f_s = series resonant frequency

Figure 12 – Curve indicating transmitted power versus frequency

Alternatively, since

$$C_j \sim \frac{1}{f_s^2}$$

from equation (1), a plot of $\frac{1}{f_s^2}$ against bias will provide a plot of KC versus bias, where K is a constant.

If the frequency is adjusted to the series resonant frequency at zero bias, the forward bias voltage (V_1) and the reverse bias voltage (V_2) required to double the transmitted power are obtained.

Using the plot of KC_j versus bias, corresponding values of KC_{j1} and KC_{j2} may be found. The value of Q may then be derived from:

$$Q = \frac{KC_{j1} + KC_{j2}}{KC_{j1} - KC_{j2}}, \text{ i.e. : } \frac{f_{s2}^2 + f_{s1}^2}{f_{s2}^2 - f_{s1}^2}$$

If $f_{s2} - f_{s1}$, is small, this can be reduced to:

$$\frac{f_s}{f_{s2} - f_{s1}}$$

without serious error.

b) *Alternative method*

The effective Q value may also be obtained by the transformed impedance measurement as given in 4.10.

4.9.1.4.5 Cut-off frequency

The cut-off frequency (f_c) at zero bias may then be obtained from:

$$f_{c(0V)} = Qf_{s(0V)} \qquad (3)$$

4.9.1.4.6 Junction capacitance at zero bias

This may be obtained using the value of the cut-off frequency (f_c) from equation (3) and R_s from equation (2):

$$C_{j(0V)} = \frac{1}{2\pi R_s f_{c(0V)}}$$

The value of junction capacitance at zero bias may then be used to calibrate the plot of $\frac{1}{f_s^2}$ versus bias in terms of C_j (see 4.9.1.4.4).

4.9.1.4.7 Series inductance

If the series inductance value is required, this may be obtained from:

$$f_{s(0V)} = \frac{1}{2\pi\sqrt{L_s C_{j(0V)}}}$$

4.9.1.4.8 Capacitance variation coefficient (γ)

The capacitance variation coefficient is defined as the normalized capacitance change over a defined range of operating conditions of forward current and reverse voltage.

The bias voltage which is required to provide the defined value of forward current is determined. Then using this forward voltage (V_F) and the defined reverse voltage (V_{-x}), corresponding values of C_j may be obtained from the $\frac{1}{f_s^2}$ or KC_j plot against the bias voltage (see 4.9.1.4.4).

If $C_{j(v_F)}$ and $C_{j(v_{-x})}$ are the capacitance values respectively, then:

$$y = \frac{C_{j(v_F)} - C_{j(v_{-x})}}{2\left[C_{j(v_F)} + C_{j(v_{-x})}\right]}$$

4.9.2 Cavity method

This method is satisfactory for measuring varactors having an effective quality factor which exceeds 15 at the measuring frequency; the results are not affected by changes in the series resistance with bias.

NOTE It is considered that this method is usable up to a measurement frequency of 15 GHz (whereas method 1, described in 4.9.1, is more practical for measurement above 6 GHz).

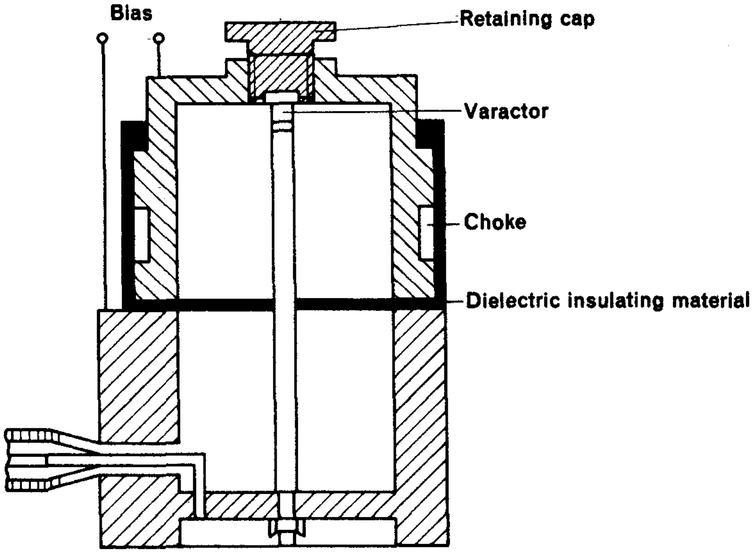


Figure 13 – Example of cavity

4.9.2.1 Theory

In this method, the effect is evaluated of a varactor diode on the resonant frequency and Q-factor of a coaxial cavity resonator about half-wavelength at the operating frequency. The diode is mounted between the centre conductor and the plane wall of the cavity resonator as shown in figure 13.

In order to limit the range of variation of the cavity resonant frequency when the junction capacitance or the diode is changed, it is essential to use a resonator having a large ratio of external to internal conductor diameter (high-characteristic impedance of the coaxial cavity).

This method will determine the junction capacitance C_{jo} and the cut-off frequency f_{co} at bias voltage V_o.

These quantities enable the determination of the series resistance r_s and the effective Q-factor Q_{eff} of the varactor.

The following characteristics must be determined for the cavity:

f_{ro} = resonant frequency of the cavity with the varactor at the bias voltage V_o

Q_{ro} = loaded Q-factor of the cavity with the varactor at the bias voltage V_o

C_p = stray capacitance of the varactor case

$C_T(V)$ = the variation of the total low-frequency capacitance of the varactor (junction capacitance) versus the bias voltage around V_o

$f_r(V)$ = the variation of the resonant frequency of the cavity with the varactor versus bias voltage around V_o

f' = the resonant frequency of the cavity when the varactor is replaced by a metallic dummy diode with the same dimensions as the diode being measured

Q' = unloaded-Q of the cavity when the varactor is replaced by the dummy diode

From the knowledge of $C_T(V)$ and $f_r(V)$, a curve can be derived which represents f_r versus C_T. This curve enables a quantity "a" to be evaluated, "a" being the slope of the curve at $C_T = C_T(V_o)$.

This junction capacitance, deduced at the bias voltage V_o is given by:

$$C_{jo} = C_T(V_o) - C_p$$

and the cut-off frequency:

$$f_{co} = 2\, a\, k\, Q_{ro}\, C_{jo}$$

where k is a correction factor introduced to take into account losses in the cavity walls; for the second TEM resonance frequency, it is given by:

$$k = \frac{1}{1 - \dfrac{Q_{ro}}{Q'}\sqrt{\dfrac{f'}{f_{ro}}}}$$

Series resistance, at the bias voltage V_o, is given by:

$$r_{so} = \frac{1}{2\pi\, f_{co}\, C_{jo}}$$

and the effective Q_{eff} at bias voltage V_o is given by:

$$Q_{eff} = \frac{f_{co}}{f_{ro}}$$

4.9.2.2 Measurements

4.9.2.2.1 Circuit diagram

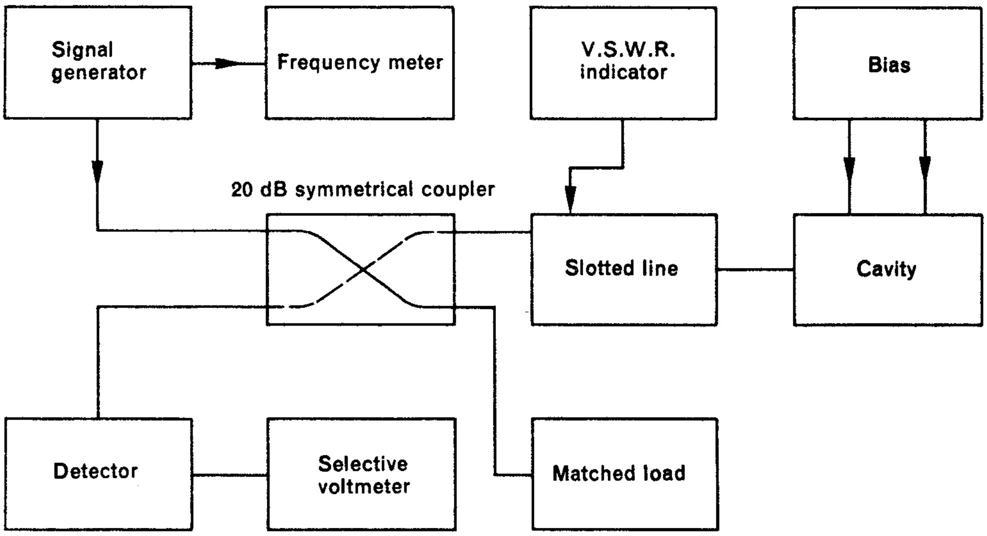


Figure 14 – Block diagram

4.9.2.2.2 Circuit description and requirements

The RF signal shall be of high-frequency stability and modulated at a low frequency appropriate to the selective voltmeter and V.S.W.R. indicator and is applied to the cavity through a 20 dB directional coupler.

The amplitude of the peak RF signal V_p must be low enough to ensure that non-linearity does not occur at the operating point of the characteristic.

The incident power at the cavity input shall not exceed the value given by the expression:

$$P = \frac{\pi \ (r+1)^2}{4\,r} \ \frac{f_{ro}^2}{f_{co}} \ C_{jo} \, V_p^2$$

where r indicates the V.S.W.R. in the slotted line at the input of the cavity. Since the limitation on the incident power is not critical, an estimated value can be used for f_{co}.

4.9.2.2.3 Measurement procedure

a) *Measurement of $f_r(V)$ and f_{ro}*

The measurement of the resonant frequency $f_r(V)$ is performed at a number of bias points around V_o (e.g. if $V_o = -6$ V, f_r can be measured at the following voltages: –4 V; –4,5 V; –5 V; –5,5 V; –6 V; –6,5 V; –7 V; –7,5 V).

The measurement is performed by varying the signal frequency and observing the value for minimum reflected power. To ensure a high accuracy, it is better to determine f_r as the average between two frequencies adjacent to f_r which have the same power from the cavity.

b) *Measurement of* Q_{ro}

Set the bias voltage to V_o and determine the value of the loaded Q_{ro} by means of V.S.W.R. measurement.

c) *Measurement of* f' *and* Q'

These values are obtained in the same way as f_r and Q_{ro} after the varactor has been replaced by a dummy diode.

These are fundamental characteristics of the cavity.

4.9.2.3 Measurement of $C_T(V)$ and C_p

The total capacitance of the varactor diode:

$$C_T(V) = C_j(V) + C_p$$

is obtained by a conventional low-frequency bridge measurement.

The value of C_p can be deduced using the expression:

$$C_p = \frac{(\varphi - V_2)^n \, C_T(V_2) - (\varphi - V_1)^n \, C_T(V_1)}{(\varphi - V_2)^n - (\varphi - V_1)^n}$$

where

V_1 and V_2 = two values of bias voltage; for reverse bias, V_1 and V_2 will be negative terms

φ = contact potential difference (e.g. 0,7 V for silicon diodes)

n = factor of non-linear dependence of C_j on V

4.9.2.4 Direct measurement of C_p

C_p can be measured directly when the ohmic contact between the internal metallic lead and the semiconductor chip has been interrupted in a varactor.

4.10 Transformed impedance method

This method is satisfactory for the measurement of diodes which are only to operate within that part of the diode characteristic in which the value of series resistance is sensibly independent of the value of the bias voltage.

4.10.1 Theory

The normalized impedance (Z) at any place in a lossless transmission line is related to the reflection coefficient (ρ) at that place by the expression:

$$Z = \frac{1+\rho}{1-\rho}$$

The form of this relation indicates that the normalized impedance and the reflection coefficient at any plane are bilinearly related; hence it may be shown that, for a lossless transformation between two impedance planes Z_1 and Z_2 we can write:

$$Z_2 = \alpha Z_1 + j\beta \tag{4}$$

where α and β are real numbers.

If two values of impedance (Z^a and Z^b) at one place which only differ in the value of their reactive components are then considered, corresponding impedance at a second plane may be written as:

$$Z_2^a = \alpha (R_1 + jX_1) + j\beta = \alpha R_1 + j\,(\alpha X_1 + \beta) \tag{5}$$

and

$$Z_2^b = \alpha (R_1 + jX_1 + \Delta X) + j\beta = \alpha R_1 + j\,(\alpha X_1 + \alpha \Delta X + \beta) \tag{6}$$

From equation (4), it will be seen that circles of constant resistance on a Smith Chart at one plane transform into the same family of circles at another, but that the resistance value is changed in the ratio α.

This transformation is pertinent to the reactance values, so that the ratio $\frac{\Delta X}{R}$ as obtained from equations (5) and (6), is seen to be independent of the transformation constants α and β.

Thus, for a transmission line which is terminated in an impedance whose reactive component is varied, the impedance locus at a plane in the measuring line which corresponds to the terminal plane also lies on a circle of constant resistance.

If the impedance plane of Z_1 is taken as being that of the diode element itself, then $\frac{\Delta X}{R}$, in any corresponding plane is the same as the value ΔQ of the diode.

Hence if:

$$\Delta X_{12} = |X_1 - X_2|, \text{ then } \frac{\Delta X_{12}}{R} = \Delta Q_{12} \text{ i.e. } |Q_1 - Q_2|$$

where the subscripts 1 and 2 correspond to the value of the parameter which is obtained at the bias voltages V_1 and V_2 respectively.

Now the effective quality factor Q at any required point may be given by:

$$Q = \Delta Q \bullet \sigma \tag{7}$$

where σ is a constant factor relating two bias points, for a given type of diode.

One of the two bias points (V_1 or V_2) can be the required value.

Derivation of σ

The value of σ_{12} may be obtained from the expression:

$$\sigma_{12} = \frac{C_1}{\Delta C_{12}} = \frac{1}{1-\left(\dfrac{\phi - V_1}{\phi - V_2}\right)^{\eta}} \tag{8}$$

where

ϕ = quasi-contact potential difference

η = factor of non-linear dependence of C on V

> EXAMPLE: For silicon varactors made by a diffusion process, η is usually given as $\frac{1}{3}$ and ϕ is of the order of 0,5 volt.
>
> If $V_1 = -4{,}5$ volts and $V_2 = -6$ volts, then $\sigma = 10$, i.e. $Q = 10\,\Delta Q$.

The value of σ may be obtained experimentally by the measurement of the capacitance variation between three closely grouped bias points, say 1, 2 and 3, so that we have ΔC_{12} and ΔC_{23}.

The value of σ may then be obtained from:

$$\sigma = \frac{1 + \dfrac{\Delta C_{23}}{\Delta C_{12}}}{1 - \dfrac{\Delta C_{23}}{\Delta C_{12}}\,\dfrac{\Delta Q_{12}}{\Delta Q_{23}}} \tag{9}$$

The corresponding values of ΔQ_{12} and ΔQ_{23} may be obtained using equations such as (10), (11), (12) or (13) as convenient.

Derivation of ΔQ

The value of ΔQ may be obtained from using either of the two expressions (10) or (12) as below:

$$\Delta Q_{12} = \sqrt{\frac{(\eta_1 - \eta_2)^2 + (\eta_1^2 - 1)(\eta_2^2 - 1)\sin^2 \Delta\Psi}{\eta_1 \eta_2}} \tag{10}$$

where

$10 \log (\eta_1^2)$ = power standing wave ratio (dB) at bias value 1

$10 \log (\eta_2^2)$ = power standing wave ratio (dB) at bias value 2

$$\Delta\Psi = \frac{M_1 - M_2}{\lambda_g} \times 360^\circ$$

where M_1 and M_2 are positions of minimum at bias values 1 and 2 respectively.

For very large values of η_1 and η_2 (viz. values usually obtained in the case of high-quality diodes), equation (10) may be simplified to:

$$\Delta Q_{12} = \sqrt{\eta_1 \eta_2} \sin \Delta\Psi \qquad (11)$$

$$\Delta Q_{12} = \sqrt{A_1\, A_2 - B_1\, B_2 \cos\theta - 2} \qquad (12)$$

where A_1 A_2 and B_1 B_2 are of the general form:

$$A_x = \frac{r_x^2 + 1}{r_x\sqrt{2}} \text{ and } B_x = \frac{r_x^2 - 1}{r_x\sqrt{2}}$$

where

r_x = V.S.W.R. at bias value x

θ = phase change of reflection coefficient between bias values 1 and 2

This formula in practice may, for an accuracy better than 1 %, be reduced to:

$$\Delta Q_{12} = \sin\frac{\theta}{2}\sqrt{r_1\, r_2} \qquad (13)$$

Considering the general formula (12) for the particular case when adjusting for r_1 = 1 (i.e. matched condition at required bias voltage), the formula reduces to:

$$\Delta Q_{12} = \frac{r_2 - 1}{\sqrt{r_2}} \qquad (14)$$

If adjustments are made to provide matched conditions at the required bias voltage, the impedance in the measuring plane will be coincidental with the unit resistance circle on the Smith Chart. It follows that this defines the plane in which the impedance Z_{in} is given by:

$$Z_{in} = Z_0\left(1 + j\frac{\Delta X}{R}\right) = Z_0(1 + j\Delta Q) \qquad (15)$$

where

Z_0 = characteristic impedance of the transmission line

The change in reactance ΔX is then measured "relative to R" as ΔQ, so that we can write:

$$\Delta Q = \frac{X_{(v)} - X_0}{R} = Q - Q_0 \qquad (16)$$

Q_0 may be found by replacing the non-linear element with a short-circuit at the plane of the diode; whence:

$$\frac{|Z_{in}|}{R_0} = \frac{|X_0|}{R} = Q_0. \qquad (17)$$

The value of Q at any other bias may then be found using equation (16).

4.10.2 Measurement procedure

The diode is inserted into a specified holder and connected to a circuit equivalent to the one shown in figure 15.

The transformation between the diode and slotted line is obtained using a variable short-circuit behind the diode and tuning stubs in front of the diode (e.g. an E-H tuner).

The bias voltage is then adjusted to the required value and transformation adjustment made so that the measured normalized impedance point is in the central region of a Smith Chart where the scale is the most open, for example to provide a match in the measuring line at the required bias value. The effect on accuracy, for non-matched conditions over a substantial impedance range about the centre of the Smith Chart, is small.

The bias voltage is then adjusted to other bias voltage points as required and, maintaining a fixed tuner adjustment, the resultant normalized impedance values are plotted on the Smith Chart.

The value of Q may then be obtained using the measured V.S.W.R. values; change in reflection phase and equations (7) to (14) as appropriate.

It is possible to obtain the effective quality factor without the derivation of σ as given in equations (8) and (9).

The transformation is made to match the diode impedance into the transmission line at the required bias, and so as to obtain an impedance point at the centre of the Smith Chart. The diode bias is then changed to other values, and corresponding impedance points on the Smith Chart obtained. This means that any reactance change in the impedance of the diode will, in the measuring plane, be coincidental with the unit resistance circle on the Smith Chart.

The diode is then replaced by an effective short-circuit and the normalized impedance is measured using the same reference plane as for the diode. An example of a diode plot is given in figure 16. The value of Q may then be derived using equations (16) and (17).

An effective short-circuit may be approximated by the use of a diode encapsulation in which the semiconductor material has been replaced by a highly-conductive material having identical geometry. In some cases, the impedance of the non-linear element (diode) can approach zero with a high forward current and, as a consequence, be acceptable as an effective short-circuit.

The plotted points obtained at the various bias values are rotated round the centre of the Smith Chart so that they coincide with the unit resistance circle. The short-circuit point is similarly treated. (Note that the normalized impedance points for high forward current fall on a constant reactance line in the plot.)

As this variation in the method depends on:

a) the effectiveness of the short-circuit;

b) the ability to obtain a match condition in the measuring plane at the standard bias voltage, and

c) the effect of the tuning element losses,

it becomes difficult to accurately determine the real part of the *Q* value of the diode. It is therefore recommended that this form of measurement be restricted to diodes having a low *Q* factor and those diodes which operate in the lower microwave frequencies.

4.10.3 Precautions to be observed

1) The variable transformer and the mount losses shall be minimized. As the losses depend on the field pattern in the vicinity of the transforming elements, which in turn depend on the diode being measured, satisfactory correction is not readily achieved.

2) If accurate values are to be obtained, the line losses, etc. which can cause serious decrease in the measured values of standing wave ratios used in equations (10) and (11), shall be determined. The transmission line length is the length between the standing wave probe position at the nearest voltage minimum and the plane of the active region of the varactor diode seated in its mount. In addition, the mount and connector loss shall be taken into account.

3) It should be verified that the series resistance is independent of varactor bias over an adequate range of the characteristic by checking that the impedance plot lies on the $\frac{R}{R_0} = 1$ circle. However, deviation from a circle may be caused by losses. An estimate of the significance of the combined losses can be made by comparing measurements using different settings of the transforming elements and different match bias values.

   It is possible to transform points in one experimental plot to points close to the centre of the chart. If losses are negligible, the results will agree. For example, in figure 16, the losses are negligible and the results for –9,0 volts and –4,0 volts, when matched at –6,0 volts, should be shown by points marked by crosses.

   An alternative method to verify the dependence of the series resistance (R_s) on bias is to calculate the values of ΔQ_{12}, ΔQ_{23} and ΔQ_{13} for the three bias values as given for equation (9) and then examine whether the values satisfy the following relation:

$$\Delta Q_{13} = \Delta Q_{12} + \Delta Q_{23} \tag{18}$$

   If this relation is satisfied within acceptable limits, then it can be assumed that the series resistance value is sensibly independent of the bias voltage. Equations (7) and (9) may then be used to evaluate *Q*.

Capacitance measurement

This measurement is made usually at non-microwave frequencies. To obtain the capacitance of the non-linear element, the cartridge capacitance shall be subtracted from the total varactor capacitance.

The simplest and most direct method of obtaining the package capacitance is to substitute a unit in which there is no contact to the semiconductor. Another method can be used, if the form of the relation between capacitance and voltage is known (see, for example, equation (19)). The cartridge capacitance may be deduced by measuring the total capacitance at an appropriate number of bias points, which yields $C_c + C(V)$ and, since the form of $C(V)$ is known, both C_c and $C(V)$ can be obtained.

$$C(V) = C(V')\left(\frac{\phi - V'}{\phi - V}\right)^{1/n} \quad \text{with } n > 0 \qquad (19)$$

NOTE Although the measurements in this subclause may be made using a standing wave detector, they may also be made by the use of an automatic impedance plotting instrument, an example of which is the automatic Smith Chart display unit. Because the value of Q is given by the normalized reactance change in a plane corresponding to the diode element for any lossless transformation, the Smith Chart may be adapted to give direct readings of Q as given in 4.11.

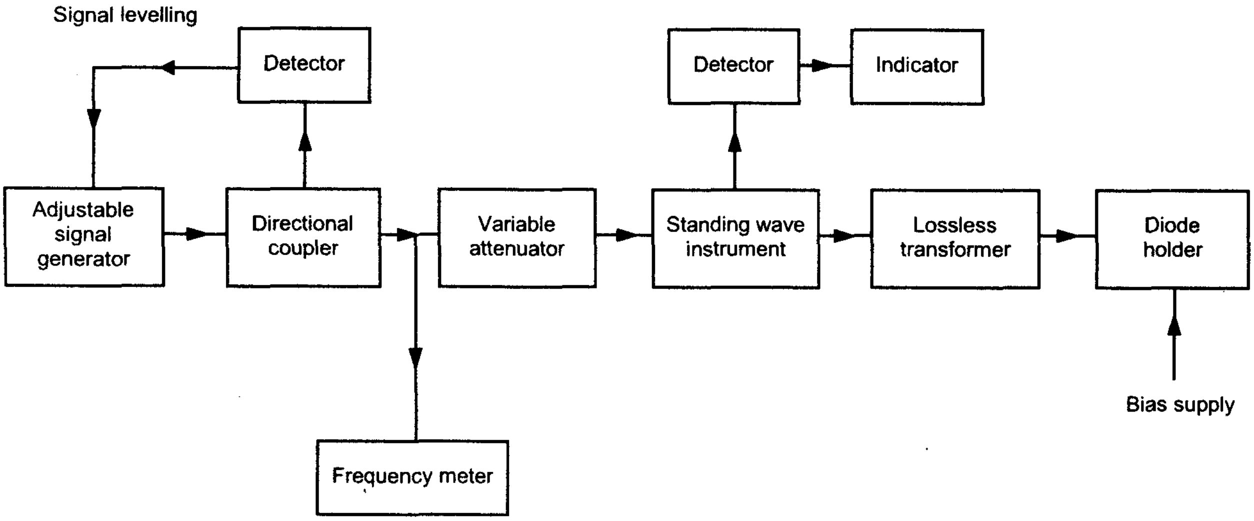
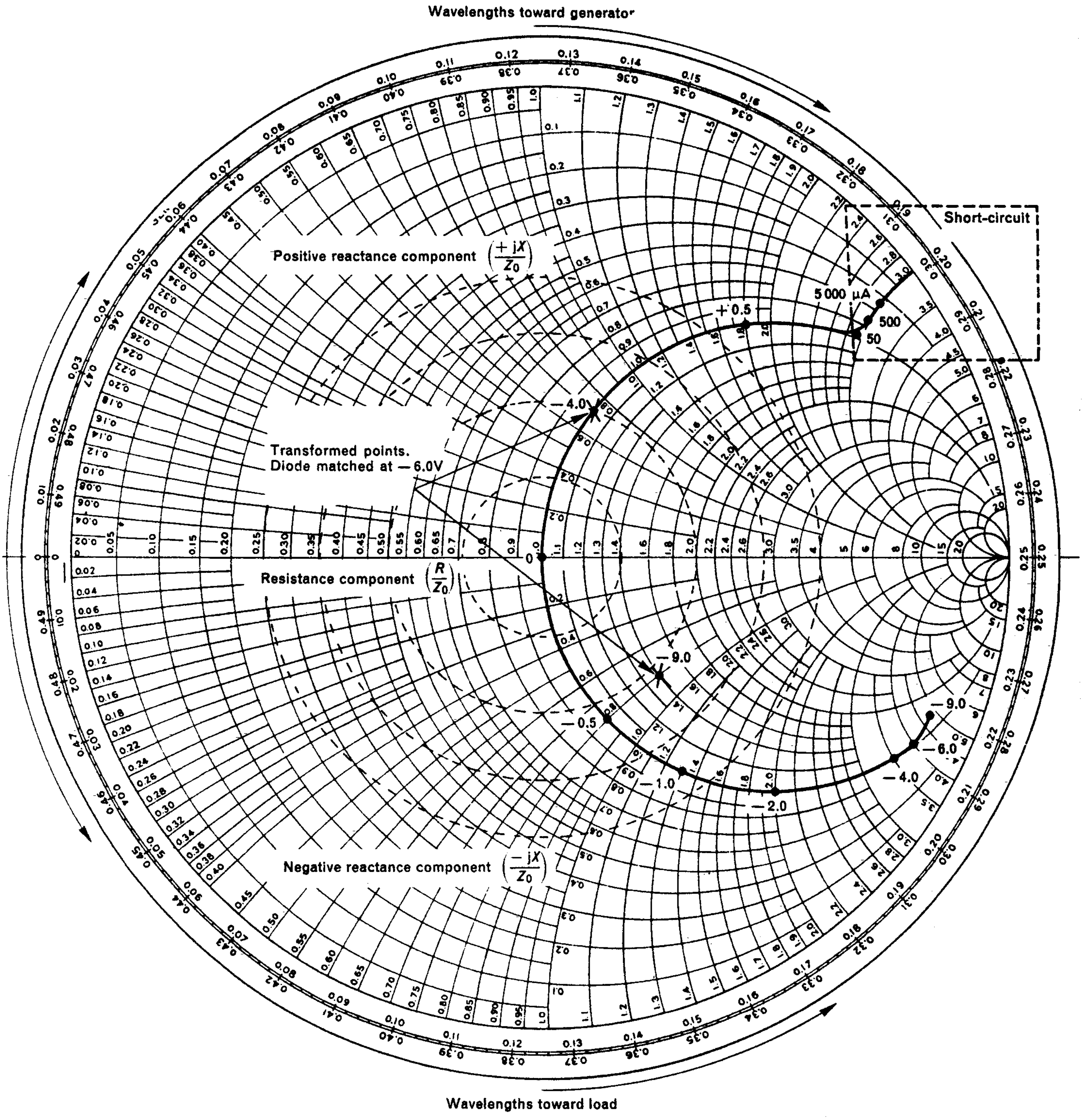


Figure 15 – Block diagram of transformed impedance measurement circuit



Frequency = 10 GHz

∅ = 0,5 V

Figure 16 – Example of plot of diode impedance as a function of bias

4.11 Method of constant quality factor circles

As it has been shown in the "Theory" section of method, given in 4.10, ΔQ is given by the normalized reactance change in a plane corresponding to the diode element for any lossless transformation; it follows that the Smith Chart may therefore be adapted to give direct readings of ΔQ from two impedance measurements for any arbitrary transformation. This may be done by introducing a grid of lines to represent fixed values of $\frac{X}{R}$ (i.e. Q).

The normalized impedance (Z) for any measuring plane is given in terms of the complex reflection coefficient (ρ) by:

$$Z = R + \mathrm{j}X = \frac{1+\rho}{1-\rho}$$

thus:

$$R = \frac{1-\rho\rho^*}{1+\rho\rho^* - \rho - \rho^*}$$

and:

$$\mathrm{j}X = \frac{\rho-\rho^*}{1+\rho\rho^* - \rho - \rho^*}$$

hence:

$$\frac{\mathrm{j}X}{R} = \frac{\rho-\rho^*}{1-\rho\rho^*} = \mathrm{j}Q$$

from which:

$$\rho\rho^* + \frac{\mathrm{j}}{Q}\rho^* - \frac{\mathrm{j}}{Q}\rho - 1 = 0 \tag{20}$$

The equation (20) represents the equation of a circle and, when comparing it with the general equation for a circle, viz.:

$$(\rho - a)(\rho^* - a^*) = K^2$$

we can deduce that the radius K is given from equation (20) by:

$$K = \sqrt{1+\frac{1}{Q^2}}$$

and having a centre displaced from the origin of co-ordinates by a vector value of $\frac{\mathrm{j}}{Q}$.

A family of circles representing constant Q may thus be constructed on a Smith Chart and these, together with the family of constant resistance circles, are sufficient to determine ΔQ. An example of the resulting chart is shown in figure 17.

When applying the chart for the diode measurement, the diagram is orientated so that the measured normalized impedance points, corresponding to the two bias conditions, appear on a constant resistance circle. The corresponding *Q* values are then obtained.

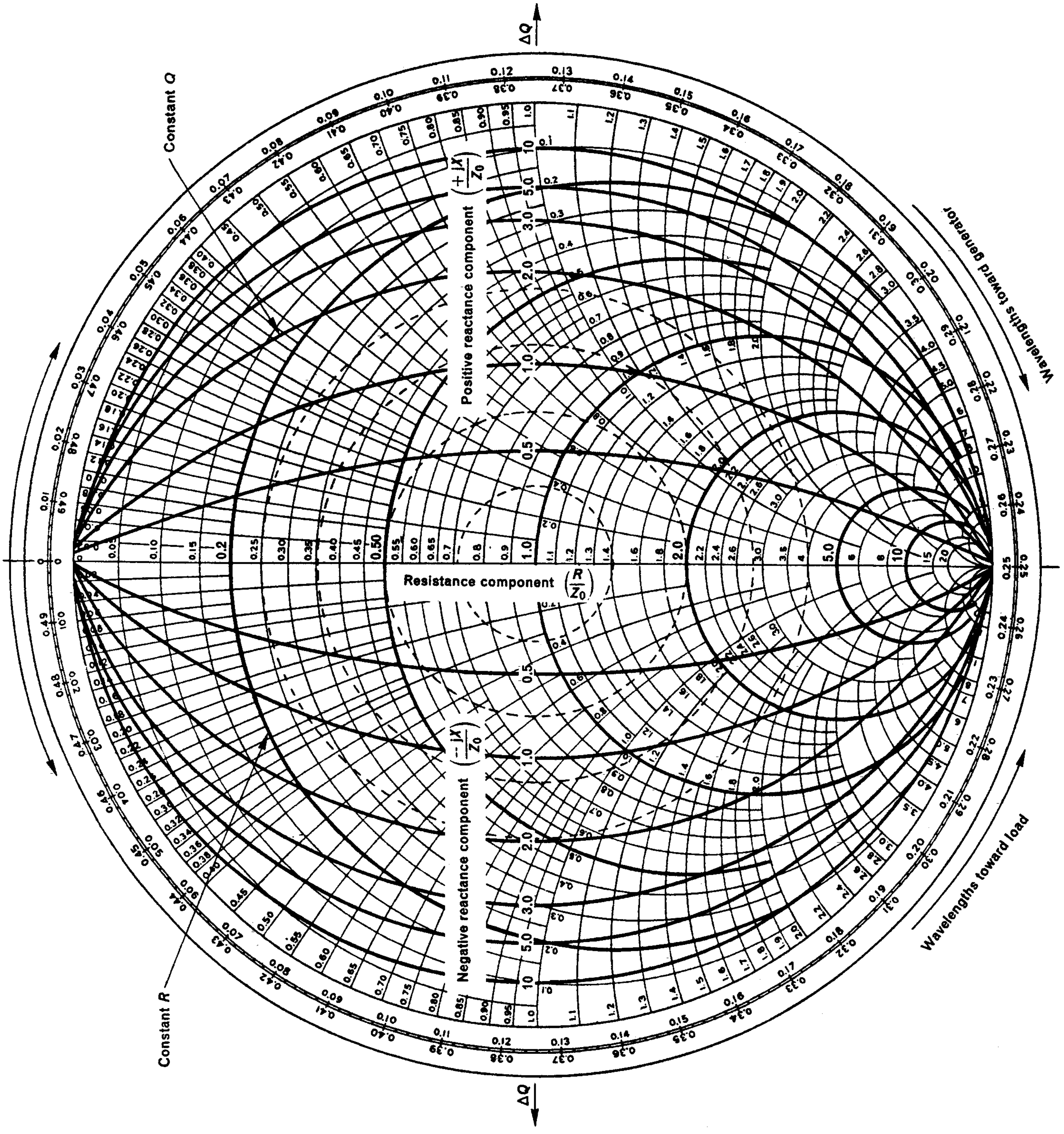

ΔQ
Constant Q
Wavelengths toward generator
Positive reactance component $\left(\frac{+jX}{Z_0}\right)$
Resistance component $\left(\frac{R}{Z_0}\right)$
Negative reactance component $\left(\frac{-jX}{Z_0}\right)$
Wavelengths toward load
Constant R
ΔQ

Figure 17 – Modified Smith Chart indicating constant *Q* and constant *R* circles

CHAPTER II: VARIABLE CAPACITANCE DIODES, SNAP-OFF DIODES AND FAST-SWITCHING SCHOTTKY DIODES

Section 2: Snap-off diodes, Schottky diodes

1 General

Snap-off (step recovery) diodes may be specified either as ambient rated or case rated or, where appropriate, as both.

2 Terminology and letter symbols

Transition time (of a snap-off diode) t_t

The time taken for the voltage across a snap-off diode to change from a specified low fraction of the total voltage step ($V_F + |V_{RM}|$) to a specified high fraction of the voltage step, when the diode is switched from forward current to reverse voltage (see figure 18).

NOTE Values of 20 % and 80 % are preferred.

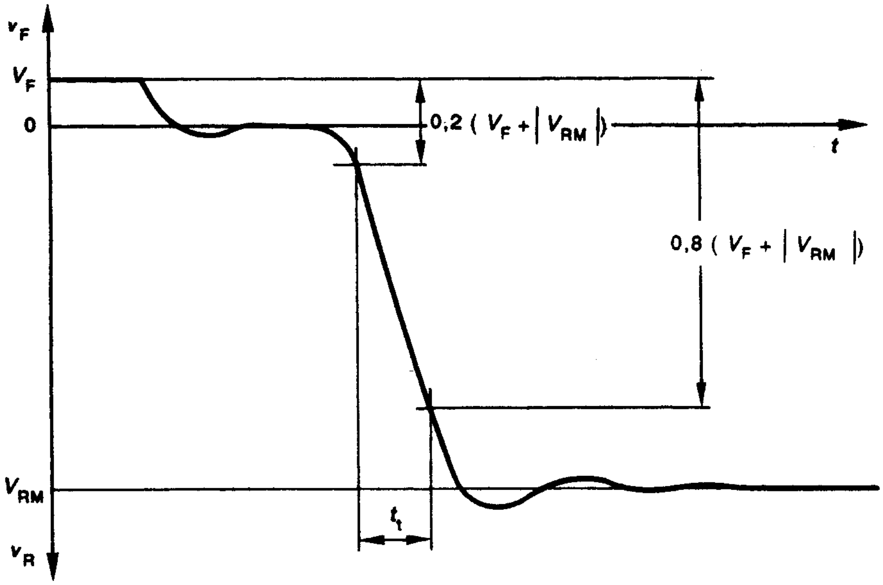


Figure 18 – Transition time t_t

(Other parameters: see clause 3.)

3 Essential ratings and characteristics

3.1 General

See 3.1, section 1.

3.2 Ratings (limiting values)

The following ratings should be stated:

3.2.1 Temperatures

3.2.1.1 Range of operating temperatures.

3.2.1.2 Range of storage temperatures.

3.2.2 Voltage and currents

The following ratings must be valid for the whole range of operating conditions as stated for the particular device.

3.2.2.1 Maximum peak reverse voltage.

3.2.2.2 Maximum mean forward current, where appropriate.

3.2.2.3 Maximum peak forward current, where appropriate.

3.2.3 Power dissipation

Maximum dissipation, under stated conditions, over the operating temperature range.

3.3 Electrical characteristics

Unless otherwise specified, the following characteristics should be stated at 25 °C:

3.3.1 Series inductance (L_s)

Typical value under specified conditions.

3.3.2 Terminal capacitance ($C_{tot} = C_j+C_p$)

Minimum and maximum values at specified bias voltage and specified frequency.

3.3.3 Junction capacitance (C_j)

Minimum and maximum values at a specified bias voltage and specified frequency. If the order of magnitude of C_p is the same as that of the terminal capacitance C_{tot}, a typical value for C_j should be given instead.

3.3.4 Series resistance

Typical or maximum value, as appropriate, under specified conditions.

3.3.5 Reverse current

Maximum value at a specified reverse voltage.

3.3.6 Stored charge or minority carrier storage time

Maximum value, under specified conditions, which may be stated either as a stored charge per unit of current (e.g. in $\frac{\text{picocoulombs}}{\text{milliamperes}}$), or as minority carrier storage time (e.g. in nanoseconds), the test circuit being also specified.

3.3.7 Transition time

Maximum value under specified conditions, the test circuit also being specified.

3.3.8 Forward voltage (where appropriate)

Maximum value for specified forward current.

3.3.9 Efficiency (where appropriate)

Minimum value, under specified conditions, of input power, input frequency, output frequency and test circuit.

3.4 Application data

- Relationship between junction capacitance and bias voltage. Typical value, in either a graphical or mathematical form.
- Cut-off frequency.

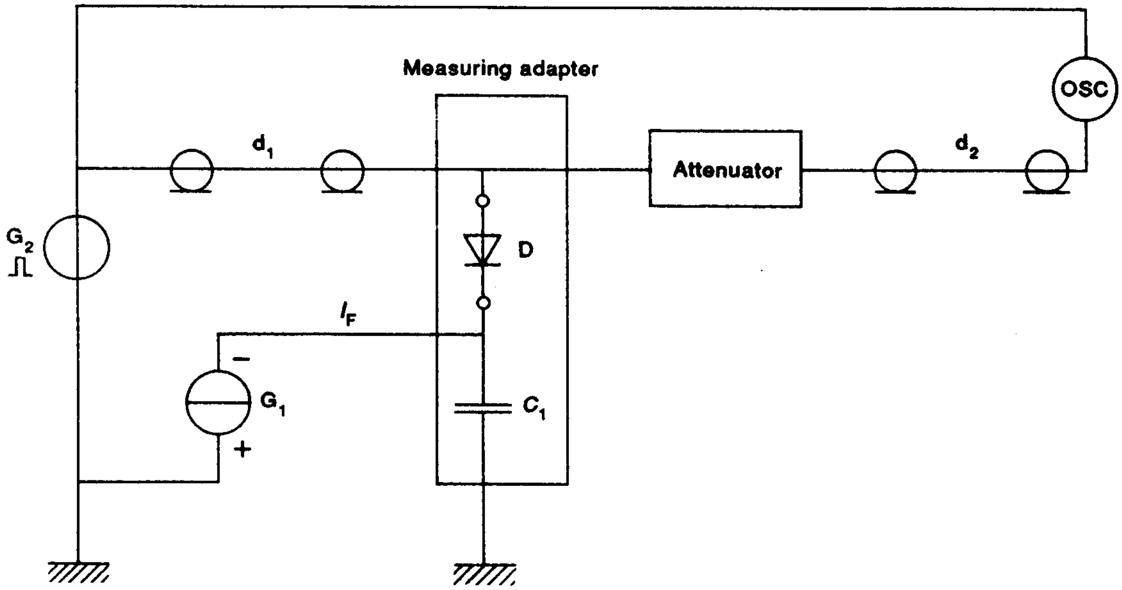
4 Measurement methods

4.1 Transition time (t_t)

a) *Purpose*

To measure the transition time t_t, for snap-off diodes.

b) *Circuit diagram*



G_1 = forward current generator (I_F)
G_2 = pulse generator
d_1 and d_2 = matched transmission lines
OSC = sampling oscilloscope

Figure 19

c) *Circuit description and requirements*

The rise time of the pulse from the generator G_2 should be equal or lower than:

$$0{,}5\frac{Q_s\,Z_0}{V_{RM}}$$

where

Q_s = stored charge
Z_0 = characteristic impedance of the line (50 Ω) at which the measurement is carried out

The pulse duration of the reverse voltage should meet the following requirement:

$$t_{VRM} \geq 1{,}5\frac{Q_s\,Z_0}{V_{RM}}$$

The measuring adapter should be in the form of a line with the characteristic impedance, Z_0 equal to 50 Ω; and should have a good matching at the input and the output in the frequency range from zero to $f > 0{,}5/t_t$.

Inductance of the measuring adapter L_s which includes inductances of the elements connecting of the diode D and the capacitor C_1 should meet the following requirement:

$$L_s \leq \frac{t_t Z_0}{5,6} - L_{sc}$$

where

L_{sc} = case inductance of the diode being measured

The capacitance of the capacitor C_1 should meet the following requirement:

$$C_1 \geq \frac{75\,Q_s}{V_{RM}}$$

A segment length of line d_1 should meet the requirement:

$$d_1 > c\frac{Q_s Z_0}{\sqrt{\varepsilon_r}\, V_{RM}}$$

where

c = rate of propagation of electromagnetic oscillations in the vacuum

ε_r = relative dielectric permeability of the line segment

The transition time of the diode being measured is calculated using the expression:

$$t_t = \sqrt{(t_{t1})^2 - (0,64\,t_r)^2}$$

where

t_{t1} = transient rise time measured on the oscilloscope between levels 0,2 and 0,8 of the voltage step

t_r = rise time of the oscilloscope between 10 % and 90 %

d) *Measurement procedure*

The forward d.c. current I_F is applied to the diode being measured from the forward current source (G_1) and a voltage pulse with the amplitude V_{RM} + V_F is set in the reverse direction.

The time interval (t_{t1}) between levels 0,2 and 0,8 of the total voltage step (V_F + | V_{RM} |) is read on the screen of the oscilloscope (see figure 20).

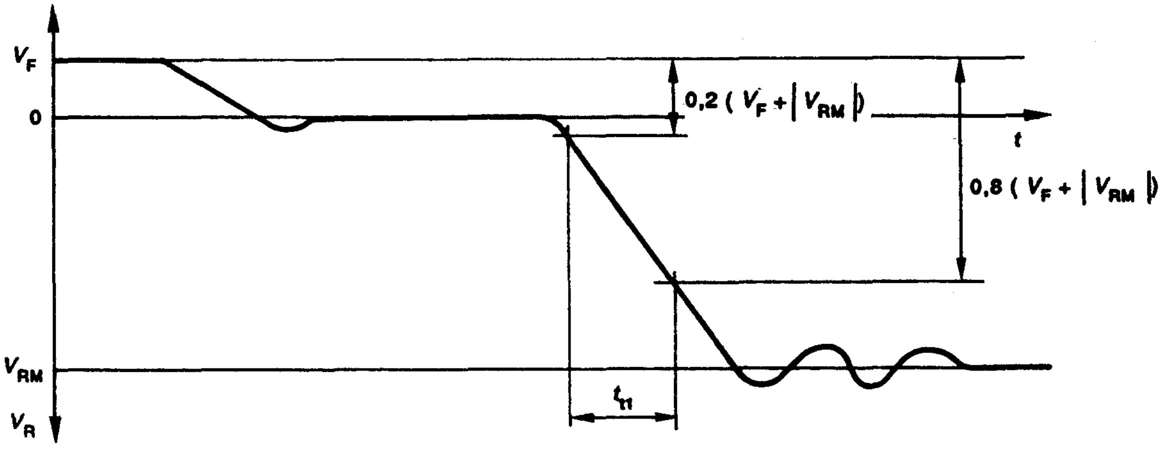


Figure 20

Using the measured time interval, the transition time is calculated from expression (1).

If 0,64 $t_r \le 0,3\ t_{t1}$, to, the time interval read on the oscilloscope is sufficiently close to the transition time of the diode.

e) *Specified conditions*

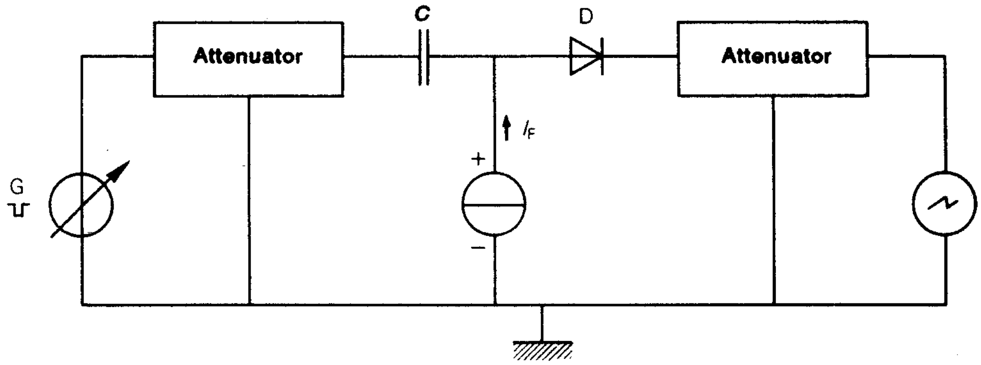
- Forward current (I_F)
- Reverse voltage (V_{RM})
- Characteristic impedance of the line (Z_0), if different from 50 Ω.
- Case inductance of the diode (L_{sc}).
- Stored charge (Q_s).

4.2 Reverse recovery time (with I_{RM} specified)

a) *Purpose*

To measure the reverse recovery time of a fast diode, e.g. with reverse recovery time less than 100 ns.

b) *Circuit diagram*



D = diode being measured

Figure 21

c) *Circuit description and requirements*

The output impedance of the generator G and the input impedance of the oscilloscope are equal to 50 Ω unless otherwise specified. The rise times of the generator and of the oscilloscope should be small compared with t_{rr}.

The pulse width should he larger than 3 t_{rr} max.

Attenuators should have a characteristic impedance of 50 Ω unless otherwise specified, and an attenuation higher than or equal to 6 dB and should be able to carry d.c. current.

The time constant $R_L\ C_L$ should be lower than 1/10 t_{rr} max., unless otherwise specified, with:

R_L = real part of the total impedance, as seen by the diode;

C_L = total capacitance of the circuit including the diode.

C should be high compared with t_{rr} max./R_L.

The impedance Z_i of the current generator should be greater than R_L.

d) *Precautions to be observed*

No special precaution.

e) *Measurement procedure*

The temperature is set to the specified value.

The current generator delivers the specified forward current I_F to the diode.

Pulses, delivered by generator G, are applied to me diode; the magnitude of the pulses is increased until the specified peak reverse current I_{RM} is reached.

The reverse recovery time t_{rr} to is the time interval between the instant at which the current passes through zero and the instant when the current is reduced from I_{RM} to the specified recovery current i_{rr} (see figure 22).

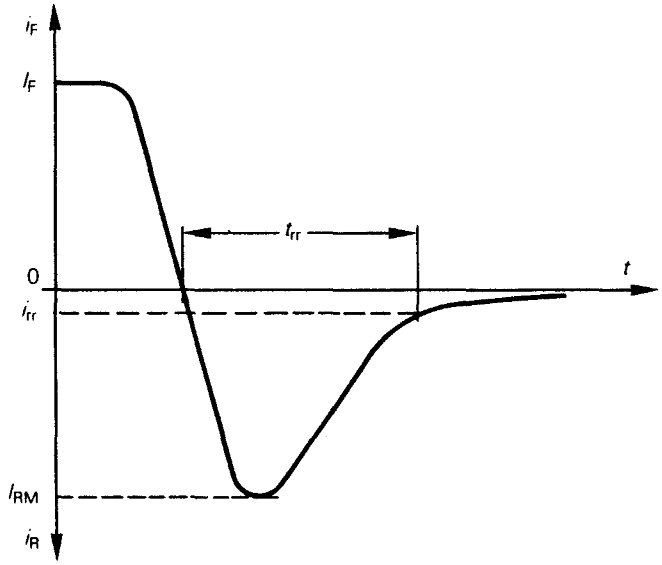


Figure 22

f) *Specified conditions*

- Ambient or reference-point temperature (t_{amb}, t_{ref}).
- Forward current (I_F)
- Peak reverse current (I_{RM})
- Reverse recovery current (i_{rr}).
  - Example of specified conditions: I_F = 10 mA
    I_{RM} = 10 mA
    i_{rr} = 1 mA

4.3 Measuring method of the excess carrier effective lifetime of diodes for fast-switching applications (snap-off diodes and Schottky diodes)

4.3.1 Purpose

To measure the excess carrier lifetime of diodes (following the Krakauer method, for example).

NOTE The conventional method has been modified so as to separate clearly the carrier lifetime owing to the carriers in excess, from the charges and discharges of the capacitance of the diode under test and of the parasitic elements (diode, case, mounting).

The carrier lifetime of a fast diode (Schottky, for example) has a very low value (theoretically zero for a Schottky diode). In practice, this measurement is generally made to determine the value of the forward current for which the parasitic elements of the diode under test contribute markedly to the carrier lifetime (guard-ring injection, etc.).

4.3.2 Principle of measurement

The diode to be measured is connected in series with a resistor, the set "diode + resistor" is supplied by a sinusoidal waveform generator (frequency ω).

The peak value of the forward current is compared with the reverse current, taking into account:

a) the charge and discharge current of the parasitic capacitance in parallel with the diode under test;

b) the electrostatic junction voltage ψ of the diode.

The values of the forward and reverse currents are calculated from the voltage measured across the resistor.

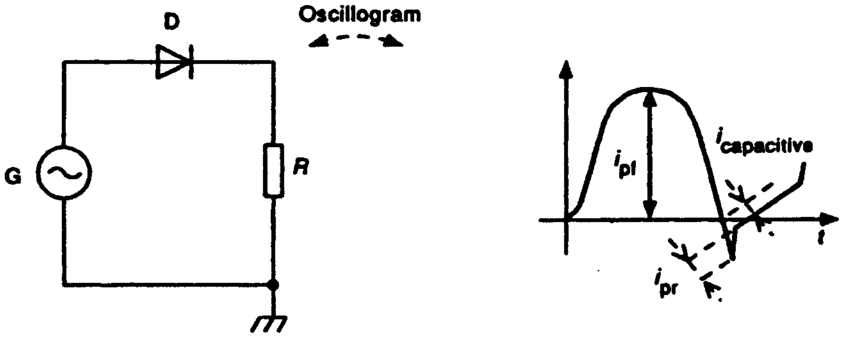


Figure 23

It can be shown that:

$$\omega\tau = \frac{i_{pr}}{i_{pf}}\left(1 - \frac{\Psi}{E_p}\right) \quad \text{and so:} \quad \tau = \frac{1}{2\pi f}\frac{i_{pr}}{i_{pf}}\left(1 - \frac{\Psi}{E_p}\right)$$

under the condition that both: $\omega\tau < 0{,}3$ and $i_{pr} > i_{capacitive}$

where

τ	is the carrier lifetime of the diode under test
f	is the frequency of the sinusoidal waveform generator, G
i_{pr}	is the peak value of the reverse current without capacitive effects
i_{pf}	is the peak value of the forward current
ψ	is the forward voltage
E_p	is the peak value of open-circuit voltage of the sinusoidal waveform generator

4.3.3 Circuit diagram

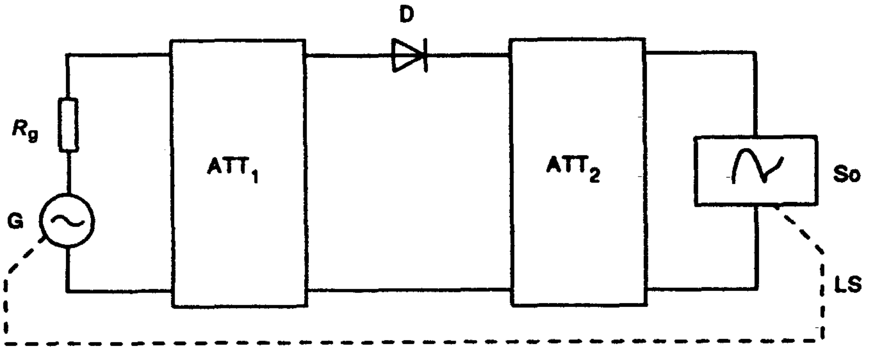


Figure 24

where

G	is the sinusoidal waveform voltage generator with frequency, f
R_g	is the internal resistance of the sinusoidal wave generator
ATT_1	is the attenuator, Zo = R_g
D	is the diode under test
ATT_2	is the attenuator, Zo = R_g
So	is the oscilloscope, Zinput = R_g
LS	is the synchronization for the oscilloscope

4.3.4 Measurement procedure

The diode to be measured is put in the test fixture similar to that shown in figure 24 (circuit diagram).

The frequency of the sinusoidal waveform generator is set and the output level adjusted to the specified value of i_{pf}.

NOTE 1 When the oscilloscope is calibrated in voltage, the value of i_{pf} can be calculated from the voltage at the input of the oscilloscope and the input impedance of the oscilloscope ($R_e = R_g$), taking into account the attenuation of ATT_2.

The value of i_{pr} corresponds to the difference between the peak value of the reverse current and the extrapolated value of the capacitive current. The value of τ is calculated with the formula from chapter II, after having determined the value of E_p and the value of ψ (for example, with a curve tracer).

NOTE 2 For the circuit diagram of figure 24, the value of e_{rms} can be measured directly on the calibrated oscilloscope when the attenuators ATT_1 and ATT_2 are directly connected (for example, a short circuit across the diode).

$$E_p = 2\sqrt{2} \times e_{rms} \left(e_{rms} = \frac{V_{rms}}{10^{(ATT1/20)}} \right)$$

Caution: It should be ascertained that:

$\omega\tau < 0,3$

$i_{pr} > i_{capacitive}$

Example: Given

R_g = 50 Ω

V_{rms} = 10 V

f = 54 MHz

ATT_1 = 10 dB, ATT_2 = 20 dB (these values are generally sufficient to reduce the effect of the mismatch appearing during the cycle after the carrier lifetime measurement).

The value of i_{pf} is read directly from the oscilloscope, and taking into account the attenuation of ATT_2, the following values are obtained:

i_{pf} = 75 mA, ψ = 1,35 V and E_p = 8,9 V.

From the oscilloscope the ratio of i_{pr} to i_{pf} is derived:

$$\frac{i_{pr}}{i_{pf}} = \frac{1}{5}$$

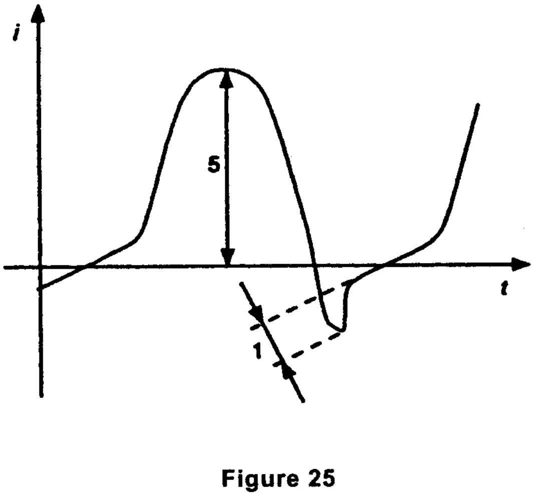


Figure 25

From the formula in chapter II it follows: τ = 500 ps

4.3.5 Requirements

The value of τ shall be within the limits specified in the relevant specification.

4.3.6 Specified conditions

Ambient or case temperature

Frequency of sine wave generator, f

Peak value of forward current, i_{pf}

Values of the elements of the circuit, and the circuit diagram with values of the elements, if different from figure 24.

CHAPTER III: MIXER DIODES AND DETECTOR DIODES

Section 1: Mixer diodes used in radar applications

1 General

Although a number of measurements may be carried out on a diode by itself, it is necessary for an assessment of diode performance to provide a standard mounting arrangement to enable satisfactory measurements to be made. Usually, the mounting takes the form of a standard holder designed for the purpose. If the holder is adjustable, all adjustments are made to conform with given measurement requirements.

In the case of reversible diodes, it may be necessary for measurements to be made with the diode connected to provide an assessment of performance in each polarity.

All microwave components used in the measuring equipment shall be checked to ensure satisfactory operation over the required frequency band. It is recommended that this be performed using swept frequency techniques.

The time constants, or pulse response characteristics of any indicating instrument, must not affect the measurement results when modulation is used.

It is essential to ensure that stray electro-magnetic fields do not significantly affect the accuracy of measurement.

In addition, any signal source used as part of the measuring circuitry shall be capable of stable operation at a signal level equivalent to the small-signal conditions of the diode being measured.

Unless otherwise stated, it is recommended that the maximum tolerances permitted for microwave signal levels should be:

a) ±0,1 % for low-power measurements required under small-signal conditions, and

b) ±1 % for high-power measurements.

Where a specified temperature is required, the temperature of the body of the measuring mount shall be measured when equilibrium conditions have been reached.

2 Terminology and letter symbols

See 3.3.

3 Essential ratings and characteristics

3.1 General

The essential ratings and characteristics for each category of diode are marked with a + sign in the following table.

- Category 1: pulse applications in systems where very short duration pulses are incident upon the diode.
- Category 2: c.w. applications or longer pulse systems.

	Categories	
	1	2
3.2 **Ratings (limiting values)**		
The following ratings should be stated:		
3.2.1 **Temperatures**		
3.2.1.1 Range of operating temperatures	+	+
3.2.1.2 Range of storage temperatures	+	+
3.2.2 **Power dissipation (including burn-out energy)**		
3.2.2.1 Maximum c.w. power under specified conditions at 25 °C		+
3.2.2.2 Maximum peak value of pulsed RF power under specified conditions at 25 °C	+	+
3.2.2.3 Burn-out energy by single pulse (or multiple pulses) under specified conditions at 25 °C	+	
3.3 **Electrical characteristics**		
Unless otherwise specified, the following characteristics should be stated at 25 °C:		
3.3.1 **Voltage standing wave ratio**		
Maximum value, when operating in a specified microwave circuit, under specified conditions	+	+
3.3.2 **IF impedance**		
Minimum and maximum values under specified conditions	+	+
3.3.3 **Conversion loss**		
Maximum value under specified conditions	+	+
3.3.4 **Overall noise factor**		
Maximum value, under specified operating conditions, using a specified microwave circuit, followed by a specified i.f. amplifier (under image frequency matched conditions)	+	+
3.3.5 **1/*f* noise**		
Maximum value, under specified operating conditions, using a specified microwave circuit followed by a specified i.f. amplifier (Doppler applications only)		+

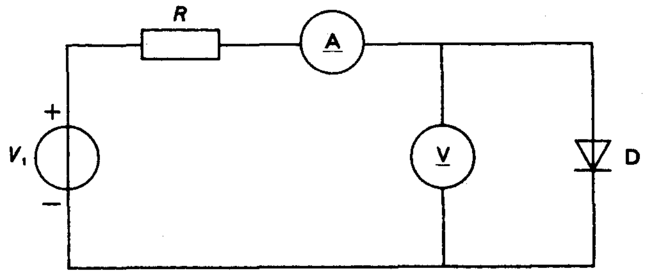
3.4 Application data

	Categories	
	1	2
3.4.1 Maximum external circuit d.c. resistance	+	+
3.4.2 Maximum and recommended values of mean forward current	+	+
3.4.3 Minimum current at specified continuous (direct) forward voltage	+	+
3.4.4 Maximum current at specified continuous (direct) reverse voltage	+	+
3.4.5 Maximum value of noise/temperature ratio under the conditions given in 3.3.4	+	+
3.4.6 Typical curve of overall noise factor versus RF input power (expressed as rectified current) under specified operating conditions	+	+
3.4.7 Typical curve of diode admittance versus frequency, the admittance being given as a normalized value in terms of a specified transmission line impedance	+	+
3.4.8 Typical curve of overall noise factor versus temperature over a specified temperature range	+	+

4 Measurement methods

4.1 Forward current (I_F)

4.1.1 Circuit diagram



R = protective resistor

D = diode being measured

Figure 26

It is essential to use a high-impedance voltmeter.

4.1.2 Measurement procedure

The specified conditions are applied and the current through the diode is measured by means of an ammeter.

4.2 Reverse current (I_R)

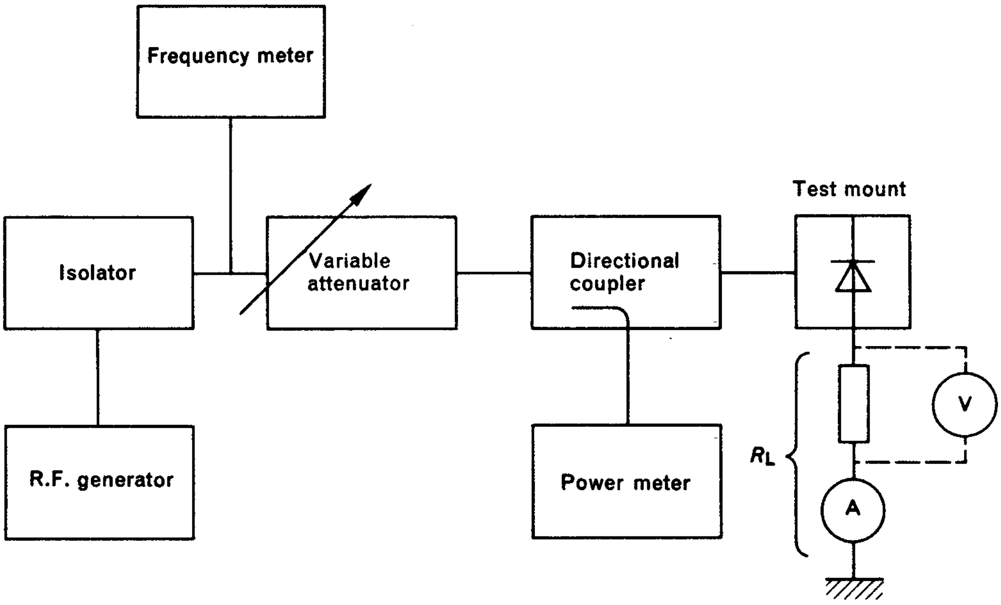
The reverse current is measured with the diode operating under given conditions by the method stated in 4.1, section 1, chapter II.

4.3 Rectified current (I_0)

4.3.1 Purpose

To measure the rectified current of a microwave diode under specified conditions.

4.3.2 Circuit diagram



R_L = diode load resistance of specified value

Figure 27

4.3.3 Circuit description and requirements

The frequency meter is loosely coupled to the line, the power meter and its associated coupler are selected to measure the specified power level incident upon the diode.

To reduce self-biasing effects, the value of the load resistance R_L, which includes the resistance of the ammeter shall be as low as possible and normally less than 100 Ω.

The value of the rectified current I_0 can be measured on the meter A or by use of a high-impedance voltmeter across the load resistance as shown by the dotted lines.

4.3.4 Measurement procedure

The diode is inserted into the measuring mount.

The RF power incident upon the diode is increased to the specified value and the rectified current I_0 is measured.

4.4 Intermediate frequency impedance (Z_{if})

Purpose

To measure the intermediate frequency impedance of a microwave diode under specified conditions.

4.4.1 Method 1: Impedance bridge method

4.4.1.1 Circuit diagram

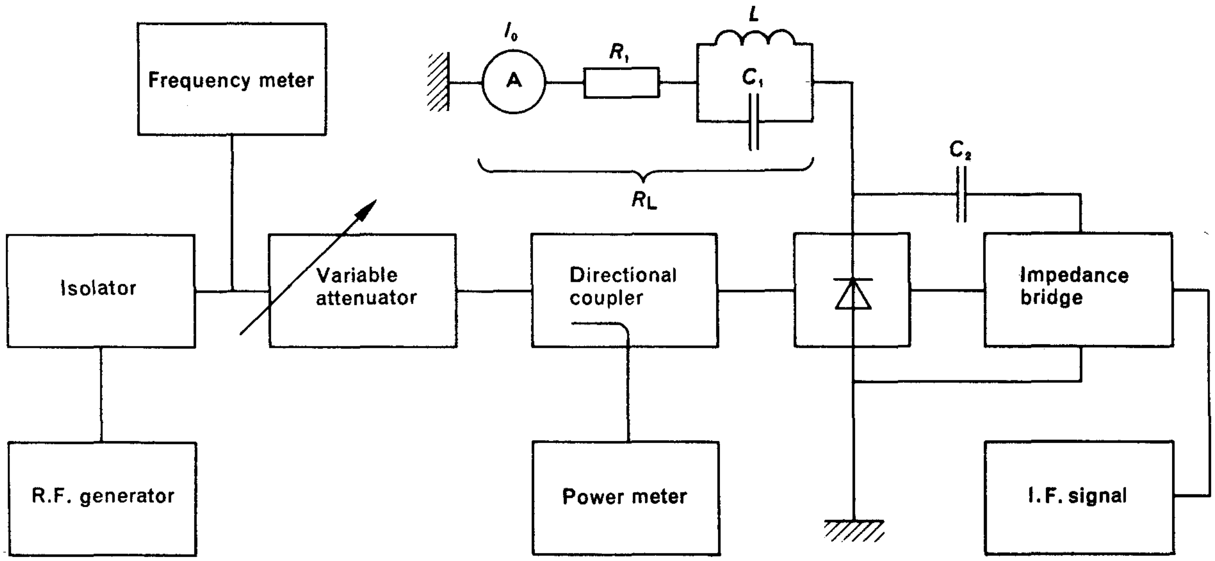


Figure 28

4.4.1.2 Circuit description and requirements

The RF generator shall be capable of operating at the signal frequency and the impedance bridge shall be capable of operating at the required intermediate frequency.

The frequency meter is loosely coupled to the line, the power meter and its associated coupler are selected to measure the specified power level incident upon the diode. Ammeter A measures the rectifier current I_0.

The values of L and C_1 are chosen so that the L C_1 circuit has a high impedance at the specified intermediate frequency.

The circuit comprising L, C_1, R_1 and ammeter A shall have a d.c. load value equal to the specified load R_L. Capacitor C_2 shall present a short circuit at the intermediate frequency.

The I.F. signal level into the bridge shall not cause more than a 1 % increase in the rectified current.

4.4.1.3 Precautions to be observed

The measurement frequency shall be sufficiently low so that the diode IF impedance can be assumed to be wholly resistive.

4.4.1.4 Measurement procedure

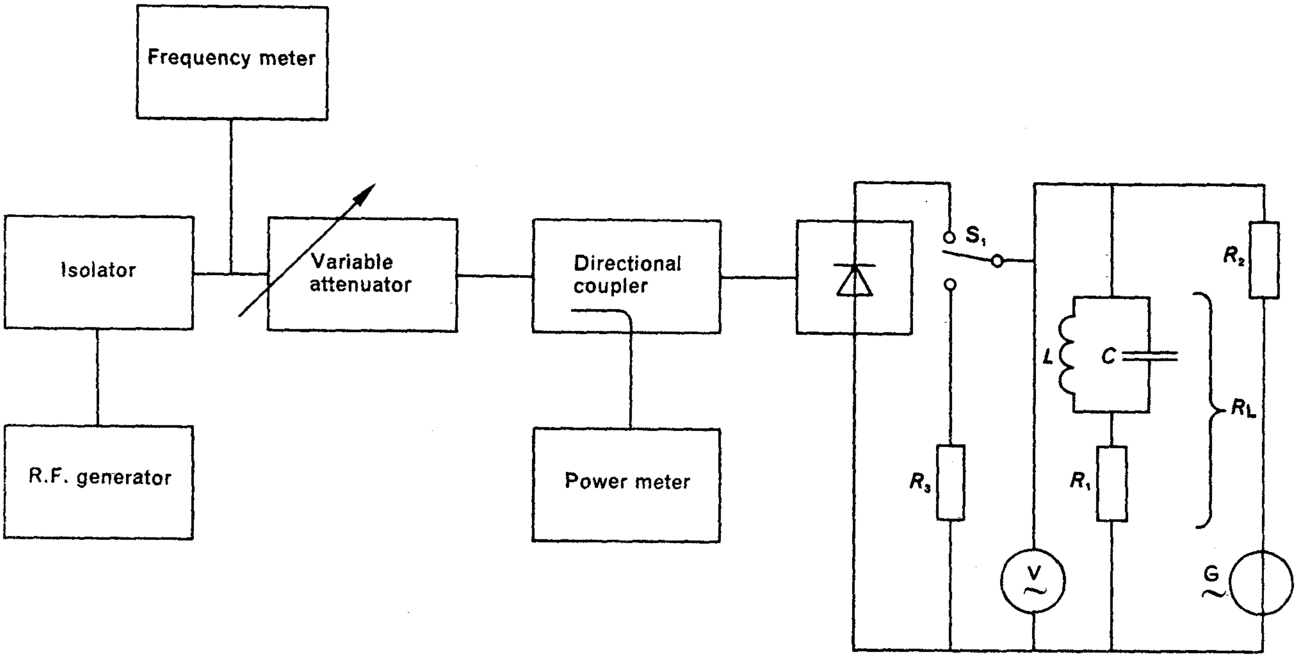
The diode is inserted into the test mount.

The bias current, where specified, is adjusted to the required value.

The signal generator is set to the required frequency and the RF power output is increased to the required power level. The impedance bridge is adjusted to the specified intermediate frequency and the diode impedance is measured.

4.4.2 Method 2: Substitution or comparison method

4.4.2.1 Circuit diagram



G = low-frequency generator

Figure 29

4.4.2.2 Circuit description and requirements

The RF generator shall be capable of operating at the intermediate frequency.

The frequency meter is loosely coupled to the line, the power meter and its associated coupler are selected to measure the specified power level incident upon the diode. The values of L and C are chosen to be in resonance at the low frequency of measurement and, together with R_1, provide an equivalent IF impedance, the same as the specified load R_L at d.c.

The low-frequency generator is coupled to the load R_L with a high resistance R_2 whose value is much greater than the diode IF impedance to provide a constant current a.c. source.

The resistor R_3 shall have a resistance of the order of the diode IF impedance. Resistors shall be non-inductive at the intermediate frequency. The a.c. voltmeter V shall have a high-input impedance.

4.4.2.3 Precautions to be observed

The power output of the low-frequency generator shall not exceed the small-signal capabilities of the diode being measured.

4.4.2.4 Measurement procedure

The diode is inserted into the test mount.

The bias current if specified is adjusted to the required value.

The signal generator is set to the requested intermediate frequency and the RF output is increased to the required power level.

The constant current low-frequency signal from the generator is adjusted to the required value.

The voltage across the diode is recorded. The low-frequency voltage is then switched from the diode using S_1 to a reference resistor (R_3) whose value is within the IF impedance values given. As the voltage across the diode is proportional to its output resistance, the measured voltage reading meter may be calibrated in terms of Z_{if}.

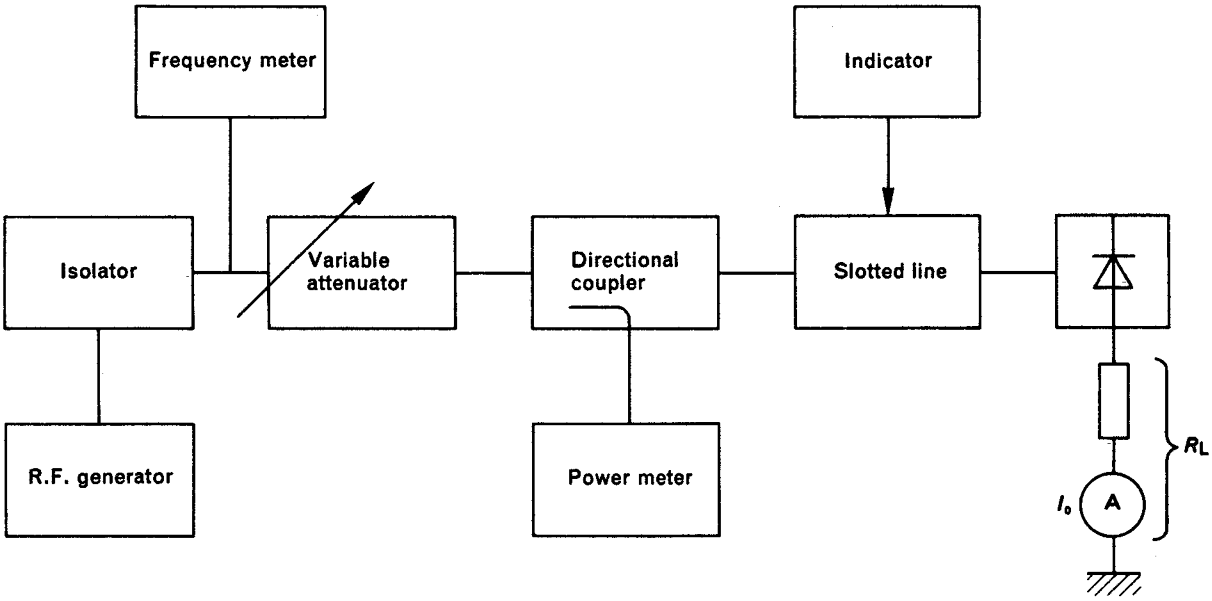
Alternatively, in place of the switch S_1 and reference resistor R_3, a number of calibrating resistors having appropriate values in the required IF impedance range may be introduced into the diode envelope and the output voltmeter calibrated accordingly.

4.5 Voltage standing wave ratio

4.5.1 Purpose

To measure the voltage standing wave ratio of a microwave diode under specified conditions.

4.5.2 Circuit diagram



R_L = stated load resistance

Figure 30

NOTE There must be sufficient filtering to prevent the indicator from responding to harmonics generated by the diode under test.

4.5.3 Circuit description and requirements

The frequency meter is loosely coupled to the line, the power meter and its associated coupler are selected to give a convenient power reading.

The coupling between the indicator probe and the slotted line shall be as loose as possible, so that the field within the line is not significantly affected.

The values of the V.S.W.R. measured are dependent upon the characteristic of the detector used in the indicator; its response to varying power levels shall be checked and calibrated.

Ammeter A measures the rectified current I_0. The load resistor R_L includes the meter resistance.

4.5.4 Measurement procedure

The diode is inserted into the measuring mount and rotated, if necessary, to optimize the performance. The RF power incident upon the diode is increased to the specified value. The values of V_{max} and V_{min} as measured on the indicator are obtained by adjustment of the slotted line.

Then: $$\text{V.S.W.R.} = \frac{V_{max}}{V_{min}}$$

Alternatively, an assessment of the V.S.W.R. may be made by an inspection of the energy which is incident upon and reflected from the diode (reflectometer). If P_i is the incident microwave power applied to the diode and P_r the reflected power, then:

$$\text{V.S.W.R.} = \frac{P_i^{1/2} + P_r^{1/2}}{P_i^{1/2} - P_r^{1/2}} \qquad (1)$$

Return loss is the ratio P_i/P_r, which may be obtained directly from an attenuator located immediately in front of the detector on the reflected-power side arm of the directional coupler used in the reflectometer. Using a waveguide switch or gate, the mixer is replaced by a short circuit in order to reflect all of the incident power. A properly tuned lossless system is insensitive to the phase of the reflection, so that the indicator reading is essentially unchanged by the motion of a moving short circuit replacing the mixer.

In this method, it is necessary to ensure that the couplers used provide a high directivity, preferably not less than 25 dB. In addition, the coefficient of coupling of the couplers must be taken into account when using expression (1). The effects of the coefficients of coupling and the directivity of the couplers may be checked by the replacement of the diode and mount by a good quality matched termination.

If it is required to express the V.S.W.R. as a magnitude of impedance or admittance, it is essential to give a reference plane within the transmission system. A reference short-circuit may be readily achieved by the use of a metallic dummy diode having the same dimensions as the diode being measured.

4.6 Overall noise factor

Theory

The noise factor (F) of any network is given by the expression:

$$F = \frac{N_1}{k T_o B G}$$

where

N_1 = output noise power

k = Boltzmann's constant = 1,38 × 10^{-23} J K^{-1}

T_o = absolute temperature. in kelvins (taken for convenience as 293 ± 5 K)

B = effective bandwidth of the network

G = power gain of network

When a signal of available input power N' is applied to the input of the network, the output noise N_2 becomes:

$$N_2 = F(k\,T_o\,B\,G) + N'G$$

and hence:

$$\frac{N_2}{N_1} = 1 + \frac{N'}{F\,k\,T_o\,B}$$

and:

$$F = \frac{N'}{k\,T_o\,B}\left[\frac{1}{\dfrac{N_2}{N_1} - 1}\right] \qquad (2)$$

If the available input power N' applied to the network to change the value of the output noise from the network, maintaining a constant gain and bandwidth of the network, the values of gain and bandwidth are removed from the expression and any measurement becomes independent of the amplifier characteristics providing they remain stable.

Circuit diagram

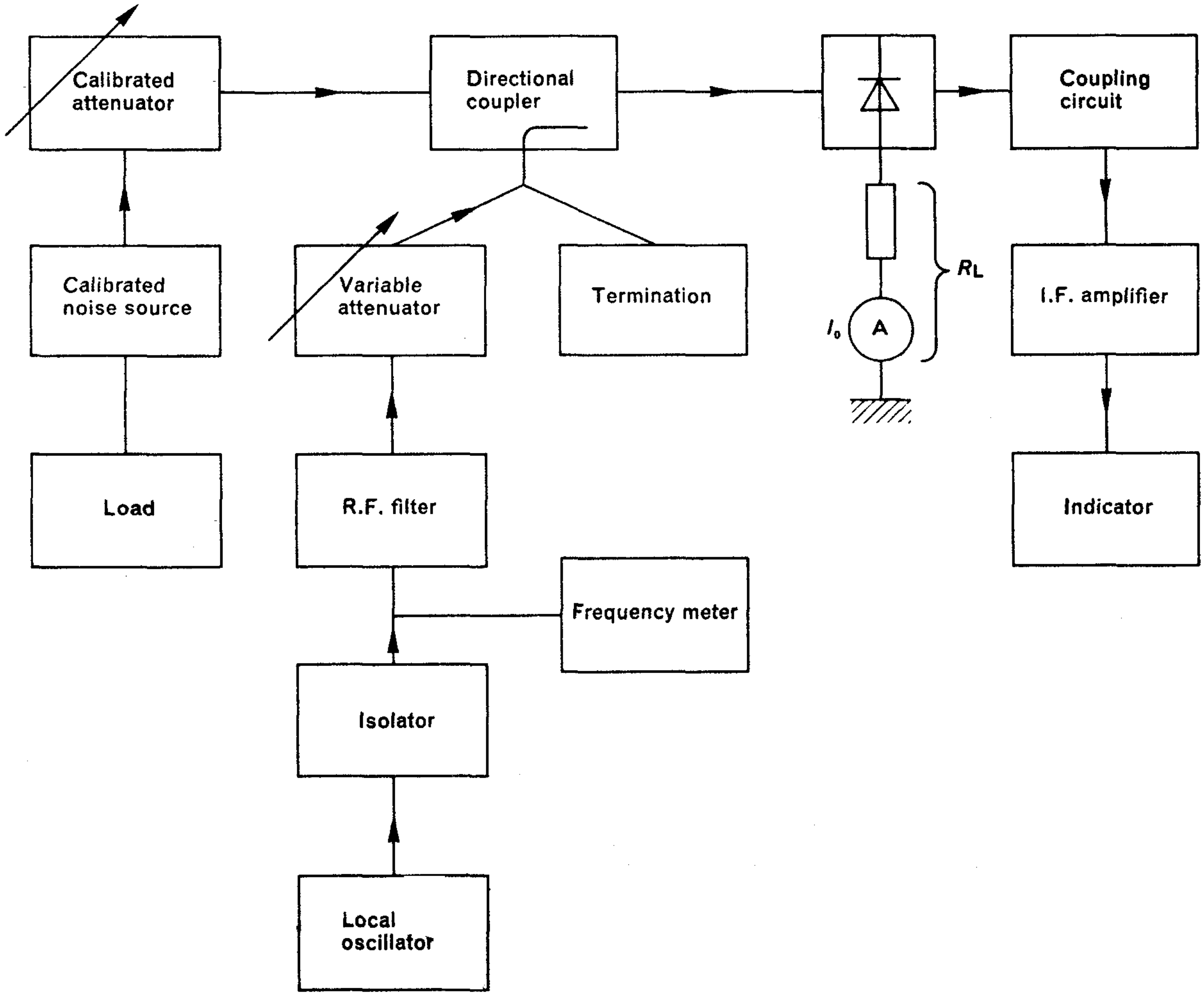


Figure 31

If the effective noise temperature of a noise power source is T in degrees kelvin, the available input power N' is by:

$$N' = k\,T_0 \left[\frac{T}{T_0} - 1\right] B$$

hence

$$F = \left|\frac{T}{T_0} - 1\right| \left[\frac{1}{\frac{N_2}{N_1} - 1}\right] \qquad (3)$$

Circuit description and requirements

The RF filter shall have a high factor Q at the local oscillator frequency, in order to provide a minimum stated rejection of the noise sidebands generated in the local oscillator (see 4.10).

The diode holder shall be as specified and the coupling circuit designed to match the diode output impedance to the IF amplifier input over the IF amplifier bandpass.

The amplifier must have stable characteristics of gain and bandwidth.

In the case of a gas discharge noise source, it is preferable that the termination connected to the calibrated noise source be matched rather than provide a short circuit, owing to the errors which may be introduced by the attenuation of the reflected noise power by the gas plasma. To remove errors which may be introduced by a change in the noise source match conditions between a "hot" and "cold" noise tube, it is preferable to "switch in" the noise source by means of a calibrated attenuator so that the noise tube may be continually in one state.

The bias supplies may need adjustment.

Measurement procedure

The measurement of overall noise factor may be made using one of the following methods:

4.6.1 Doubling the output method

The diode is fitted into a mount connected to the input of a specified amplifier.

The operating conditions are adjusted to the specified values. The calibrated attenuator is set to provide maximum attenuation so that negligible power from the noise source is received by the diode. The gain of the amplifier is adjusted to provide a convenient level of output power, as shown on the indicator. The calibrated attenuator is then adjusted so that sufficient power from the noise source is applied to the diode, to provide a reading on the indicator which is double the original value. The noise power from the noise source is then equal to the noise in the network, hence the value of network noise power can be determined directly.

The doubling of the output noise power may be conveniently checked by the use of a 3 dB attenuator in the IF amplifier. Care must be taken to ensure that the 3 dB attenuator is matched into the circuit.

Thus: $N_2 = 2\ N_1$, and equation (2) becomes: $F_o = \frac{N'}{k\ T_o\ B}\left[\frac{1}{a_{rf}}\right]$

where a_{rf} is the RF attenuation

Since:

$$N' = k\ T_o\ B\left[\frac{T}{T_o} - 1\right],$$

then:

$$F_o = \frac{\frac{T}{T_o} - 1}{a_{rf}}$$

When the noise source power is available at both signal and image frequencies, the noise figure will be equal to twice the applied noise power N', i.e.:

$$F_o = \frac{[1 + r]\left[\frac{T}{T_o} - 1\right]}{a_{rf}}$$

where

$$r = \frac{\text{gain at image frequencies}}{\text{gain at signal frequencies}} = 1$$

which, expressed in decibels, becomes:

$$F_o\ (\text{dB}) = 10\ \log_{10}\ (1 + r) + 10\ \log_{10}\left[\frac{T}{T_o} - 1\right] - a_{rf}$$

where a_{rf} is expressed in decibels.

4.6.2 IF attenuation method

The diode is fitted as in 4.6.1.

In this method, an IF attenuator is included in the circuit (usually between the main and preamplifier sections which make up the amplifier as shown in figure 31). Care must be taken to ensure the correct match of the IF attenuator into the circuit.

The method is similar to that in 4.6.1 except that, when the power from the noise source is applied to the diode by adjustment of the calibrated RF attenuator so as to double the output power, the IF attenuator is adjusted to return the power output level shown on the indicator to its original value.

Hence:

$$N_1 = \frac{N_2}{a_{if}}$$

where a_{if} is the IF attenuation

Then:

$$F_o = \left[\frac{T}{T_o} - 1\right]\left[\frac{1}{a_{if} - 1}\right]$$

If the noise source power is available at both signal and image frequencies, then:

$$F_o = [1 + r]\left[\frac{T}{T_o} - 1\right]\left[\frac{1}{a_{if} - 1}\right]$$

which, expressed in decibels, gives:

$$F_o\ (\mathrm{dB}) = 10 \log_{10} (1 + r) + 10 \log_{10}\left[\frac{T}{T_o} - 1\right] - 10 \log_{10} [a_{if} - 1] \tag{4}$$

where a_{if} is expressed in decibels in equation (4).

4.6.3 Output power method

The diode is fitted as in 4.6.1 and the procedure is similar, except that the doubling of the power output is not required. Any suitable power levels may be shown on the indicator provided that the indicated output power ratio N_2/N_1 is measurable within the square law part of the detector characteristic.

In this case, equation (3) may be used directly.

Thus:

$$F_o = \left[\frac{T}{T_o} - 1\right]\left[\frac{1}{\frac{N_2}{N_1} - 1}\right]$$

If the noise source power is available at both signal and image frequencies, then:

$$F_o = [1 + r]\left[\frac{T}{T_o} - 1\right]\left[\frac{1}{\frac{N_2}{N_1} - 1}\right]$$

which, expressed in decibels, gives:

$$F_o\ (\mathrm{dB}) = 10 \log_{10} (1 + r) + 10 \log_{10}\left[\frac{T}{T_o} - 1\right] - 10 \log_{10}\left[\frac{N_2}{N_1} - 1\right].$$

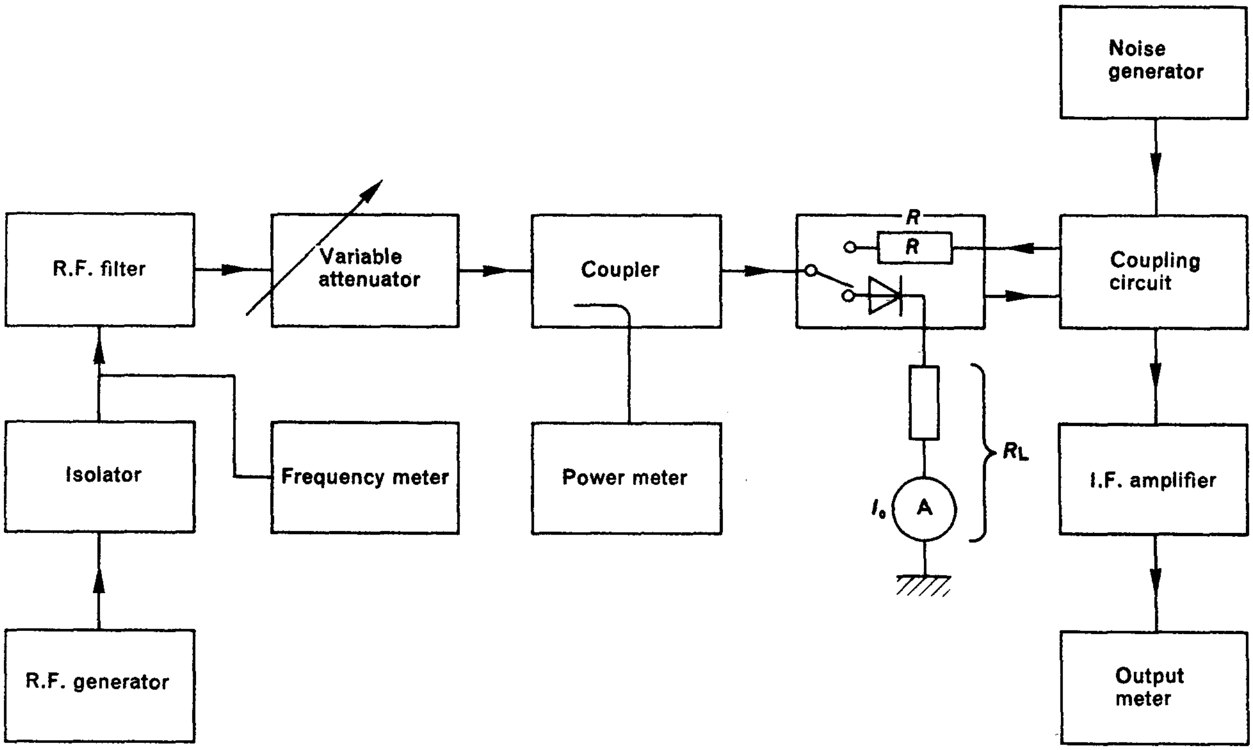
4.7 Output noise ratio

4.7.1 Direct measurement method

4.7.1.1 Purpose

To measure the output noise ratio of a microwave diode under specified conditions of frequency and bias.

4.7.1.2 Circuit diagram



R = non-inductive reference resistor

Figure 32

4.7.1.3 Circuit description and requirements

The RF filter and diode measurement mount must conform to the requirements given in 4.6. If more accuracy is required, means should be provided to tune the coupling circuit for each individual diode. The coupling circuit shall be non-dissipative.

The gain and bandwidth of the IF amplifier shall be specified. The noise factor of the amplifier must be lower than the expected noise output value of the diode being measured.

The output conductance of the mixer shall be equal to that of the diode being measured. For convenience, a number of reference resistors (covering the IF impedance range expected of the diodes under measurement) shall be available; they shall be mounted in a position which is physically and electrically equivalent to that of the diode.

4.7.1.4 Measurement procedure

The diode is mounted in a specified measurement mount, under specified operating conditions. The noise output from the diode is applied to the amplifier having known characteristics and measured in the output meter. This noise is compared with the injected noise developed across the reference standard resistor mounted in the measuring mount in place of the diode, all other conditions remaining the same.

The output meter may be calibrated in terms of output noise ratio by applying various values of noise current through the reference standard resistor. A temperature-limited saturated thermoionic diode may be used to generate the noise current.

The output noise ratio is given by:

$$N_r = \frac{e\,I}{2\,k\,g\,T_o}\left(\frac{N_2}{N_1} - 1\right) + 1$$

where

e = elementary charge ($1{,}6 \times 10^{-19}$ C)

k = Boltzmann's constant ($1{,}38 \times 10^{-23}$ J K^{-1})

I = average (d.c.) anode current of noise diode (A)

T_o = reference noise temperature (K)

g = mixer IF output conductance (usually expressed in siemens or ohms of its reciprocal)

N_2 = indicated output with diode input

N_1 = indicated output with reference resistor input

If $N_2 = 2N_1$:

$$N_r = \frac{e\,I}{2\,k\,g\,T_o} + 1$$

4.7.2 Calculated value

As the measured value, as given in 4.7.1, is so dependent on stringent measurement circuit requirements, it is sometimes more accurate to derive the output noise ratio (N_r) from the measurements of overall noise factor (F_o) and conversion loss (L_c), provided the latter has been measured, in which case:

$$N_r = \frac{F_o}{L_c} - F_{if} + 1$$

where F_{if} is the noise factor of IF amplifier.

4.8 Conversion loss

Purpose

To measure the conversion loss of a microwave diode under specified conditions.

4.8.1 DC incremental method

4.8.1.1 Circuit diagram

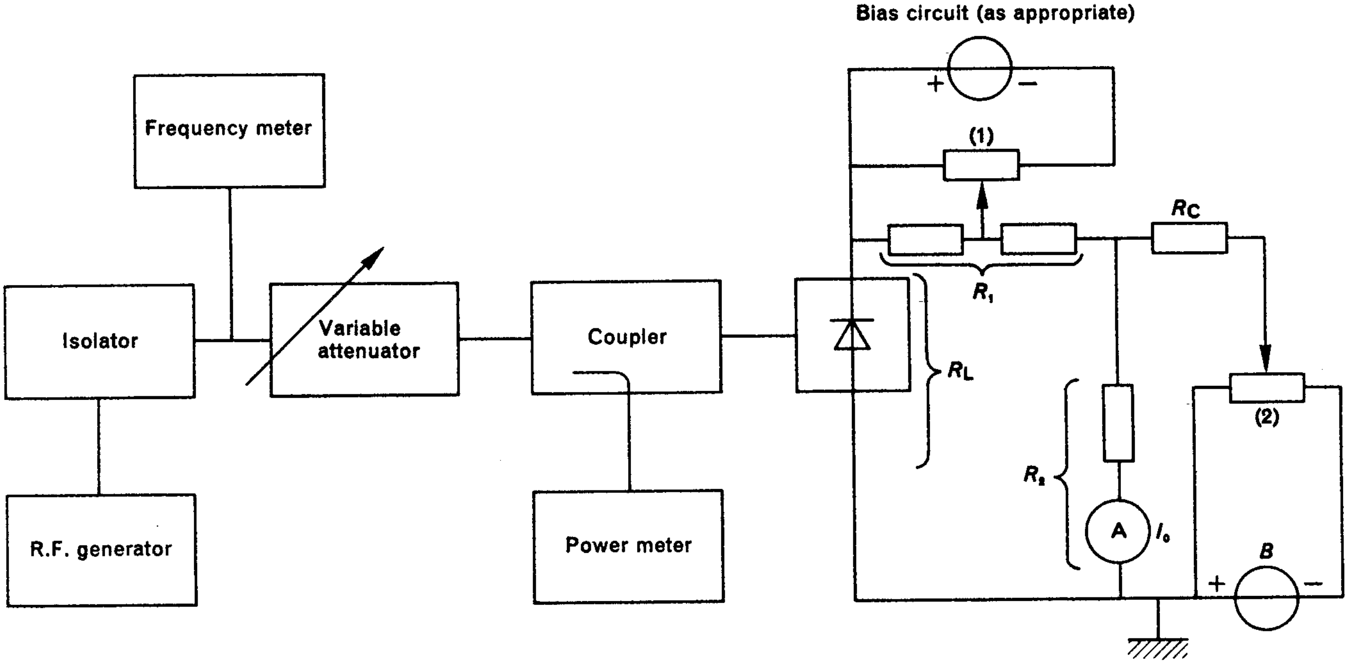


Figure 33

4.8.1.2 Circuit description and requirements

$R_L = R_1 + R_2$ = specified IF load resistance

R_1 = specified d.c. load resistance

Both the microwave power meter and the ammeter used to read the rectified current (I_0) must be capable of accurate indication of small changes. Alternatively, a calibrated variable attenuator may be used to produce an accurately known change of microwave power.

R_c must be larger than about 100 kΩ. Alternatively, en electronically regulated constant-current source may be substituted for this resistor, the battery, and potentiometer 2. The resistance between the mixer and the tap of potentiometer 1 is much lower than R_1.

4.8.1.3 Precautions to be observed

No special precautions.

4.8.1.4 Measurement procedure

The diode is inserted into the measurement circuit as shown in figure 33 and operated under specified conditions. A known low level of microwave power (P) is applied to the diode. The potentiometer (2) is adjusted so that the current supplied from the d.c. source (B) reduces the indicated rectified current (I_0) to zero. The applied microwave power is then changed by a small amount (ΔP) and the resulting small change in rectified current (ΔI_0) is measured.

The conversion loss is then derived from the expression:

$$L_c = \frac{2}{P_0 R_L^2 \frac{1}{Z_{if}} \left[\frac{\Delta I_0}{\Delta P}\right]^2 \left[\frac{1}{R_L} + \frac{1}{Z_{if}}\right]^2}$$

where

ΔP = small change in microwave power

ΔI_0 = corresponding change in rectified current

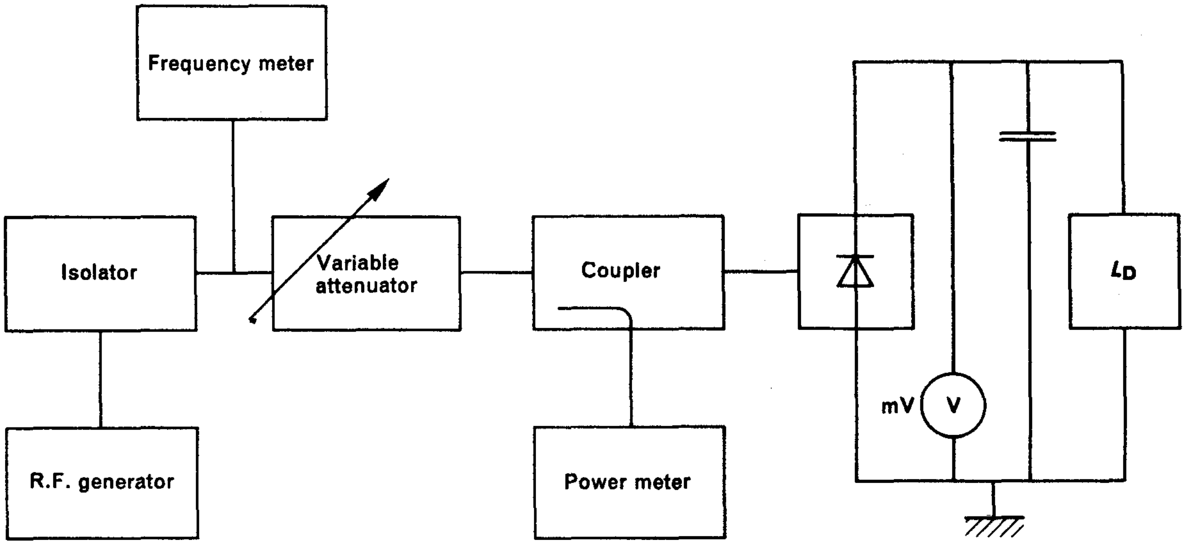
P_0 = average power $P + \frac{\Delta P}{2}$

Z_{ir} = IF impedance of standard diode

The d.c. incremental method is not readily adapted for rapid production testing, but it is used mainly to establish an absolute calibration of standard diodes. These standard diodes may then be used to calibrate the amplitude modulation method (see 4.8.2).

4.8.2 Amplitude modulation method

4.8.2.1 Circuit diagram



L_D = diode circuit providing d.c. and modulation frequency impedances as specified

Figure 34

4.8.2.2 Circuit description and requirements

R_L is the d.c. load resistance to comply with the following requirements:

$$\frac{R_L}{2} < Z_{if} < 2R_L$$

(this approximation leads to an error smaller than 0,5 dB).

The modulator may be realized by means of an adjustable attenuator driven by a PIN diode. It may be replaced by a direct modulation of the signal source, but in this case, as an accurate assessment of the value of the modulation coefficient is essential, some difficulties may be encountered. The bias supplies may need adjustment.

4.8.2.3 *Precaution:* Modulation coefficient shall not exceed 10 %.

4.8.2.4 Measurement procedure

The diode is inserted into the measurement circuit as shown in figure 34, and operated under specified conditions. The microwave power incident upon the diode is modulated in amplitude at a specified low frequency by a specified amount. The modulation envelope is detected by the diode and an a.c. voltage developed across the diode load. Knowing the percentage of modulation and the signal source power, the conversion loss may be obtained from:

$$L_c = \frac{m^2 P R_L}{V^2}$$

where

m = modulation coefficient (not more than 10 %)

P = mean power on the diode

R_L = load resistance of the diode

V = low frequency a.c. voltage across R_L

This method may be used as an absolute measurement or as a relative comparison method. In the case of a relative assessment, standard diodes as obtained using the d.c. incremental method (4.8.1) may be used.

As m^2, P and R_L are constants of the measurement circuit, there will be no need to assess their value when making relative measurements.

However, if the amplitude modulation method is used to obtain absolute measurements, it is essential to obtain an accurate measurement of m, P *and* R_L.

4.9 Burnout energy

4.9.1 Purpose

To determine the change in noise output of a microwave diode caused by application of RF or pulse energy.

4.9.2 Circuit diagram

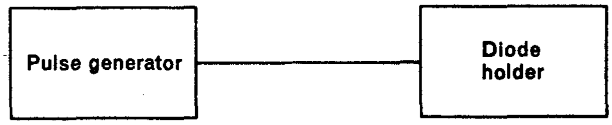


Figure 35

4.9.3 Circuit description and requirements

The pulse or RF generator is matched to the transmission line connected to the diode measuring mount. The specified power or pulse energy is the power or energy available from the transmission line. The actual dissipation within the diode depends on the transmission line impedance and on the measuring mount geometry, both of which must be specified.

4.9.4 Precautions to be observed

Where mechanical switch contacts are used, care must be taken to ensure that possible variations in contact resistance do not affect the severity of the test conditions.

If the test is carried out using low repetition rates, less than 200 Hz, a mercury-wetted relay type switch is recommended.

4.9.5 Measurement procedure

The diode shall be subjected to one of the following tests as appropriate; after test, the diode shall be measured to determine the change in the noise output produced.

4.9.5.1 Burnout by repetitive pulses

The diode is subjected to a specified number of pulses of specified duration (which is shorter than the thermal time constant of the diode junction), specified repetition rate, having a specified energy content. The pulse polarity shall be that which causes a current to flow in the direction providing the most severe effect.

4.9.5.2 Burnout by single pulse

The diode is subjected to a pulse having a specified energy content and having a specified duration (shorter than the thermal time constant of the diode junction). Alternatively, the pulse generating circuit may include a pulse-forming network which is charged to a given voltage (corresponding to the required energy value) and a contact to the diode is made by any suitable means so that a current flows through the diode in that direction which produces the most severe effect.

4.9.5.3 Burnout by C.W. or by RF pulses

The diode is fitted into the specified measuring mount and operated under specified conditions. The specified C.W. or the specified RF pulse power is applied to the diode for the specified period of time. This power must be matched to the diode input.

4.10 *Q* value of cavity required to provide a stated reduction of the noise power which a local oscillator provides at a mixer crystal output

If the noise output from a local oscillator is given by a value N (W/MHz) for a stated drive level, the equivalent (N.T.R.) noise temperature ratio (t_o) at the mixed output may be expressed by:

$$t_o = \frac{N\ (\mathrm{W/MHz})}{L_c \times kTB}$$

where L_c is the conversion loss of the mixer as power ratio.

A 290 K and at 4×10^{-15} (W/MHz):

$$t_o = \frac{N}{L_c \times 4 \times 10^{-15}}$$

If, for example, the conversion loss (L_c) of the diode is 6,3 dB, this is equivalent to 4,3 times in power, and

$$t_o = \frac{N}{17{,}2 \times 10^{-15}}$$

The overall noise factor (F), with no local oscillator noise, is given by:

$$F = L_c\,(N_{if} - 1 + t_r)$$

where

N_{if} = receiver noise factor value

t_r = mixer diode N.T.R. value

both expressed as power ratios

This expression may be written as $L_c\,t_1$, where t_1 is equal to the term within brackets.

If it is desired to reduce the noise power contributed by the local oscillator in the diode output by n times, the new value of t_o, say t_o^1, is given by t_1/n.

Hence:

$$\frac{t_o}{t_o^1} = \frac{Nn}{4L_c t_1 \times 10^{-15}} \qquad (5)$$

Now the power response of a cavity is given by:

$$\frac{1}{1+\left[\frac{2\,f_{\mathrm{if}}\,Q_{\mathrm{L}}}{f_{\mathrm{o}}}\right]^{2}}$$

where

f_{if} = IF. frequency of receiver

Q_{L} = loaded Q of cavity

f_{o} = cavity resonant frequency

Combining this expression with (5):

$$\frac{1}{1+\left[\frac{2\,f_{\mathrm{if}}\,Q_{\mathrm{L}}}{f_{\mathrm{o}}}\right]^{2}}=\frac{4\,L_{\mathrm{c}}\,t_{1}\times 10^{-15}}{Nn}$$

and:

$$Q_{\mathrm{L}}=\frac{f_{\mathrm{o}}}{2f_{\mathrm{if}}}\left[\frac{Nn}{4L_{\mathrm{c}}t_{1}\times 10^{-15}}-1\right]^{1/2}$$

EXAMPLE:

Required to reduce the noise contributed by a local oscillator by 10 times.

Noise power from local oscillator (N) = 8 × 10^{-13} W/MHz for a given diode drive.

Diode conversion loss (L_{c}) = 6,3 dB = 4,3 times.

Diode N.T.R. (t_{r}) = 1,2 times.

Receiver noise factor = 2 dB (N_{if}) = 1,6 times.

Receiver IF frequency (f_{if}) = 30 MHz.

Local oscillator operates at 10 GHz (f_{o}).

Then:

$$t_1 = 1{,}6-1 + 1{,}2 = 1{,}8$$

$$Q_{\mathrm{L}}=\frac{10^{10}}{2\times 30\times 10^{6}}\left[\frac{8\times 10^{-13}\times 10^{1}}{4{,}3\times 4\times 10^{-15}\times 1{,}8}-1\right]^{1/2}=2\,680$$

4.11 IF amplifier noise figure

Measurement procedure

The noise figure of the IF amplifier may be determined by the procedure given in 4.6.1. The circuit arrangement, centre frequency and bandwidth are determined by the IF frequency required.

The noise figure of the amplifier can be expressed as follows:

$$F_{\text{if}} = \frac{N'}{k\,T_o\,B}\left[\frac{1}{\dfrac{N_2}{N_1}-1}\right]$$

which, when $N_2 = 2N_1$ adjustment as in 4.6.1, becomes:

$$F_{\text{if}} = \frac{N'}{k\,T_o\,B}$$

If a temperature limited noise diode is used as the input noise applied through the amplifier input resistor, then:

$$N' = \frac{eIRB}{2}$$

Then:

$$F_{\text{if}} = \frac{eIR}{kT_o} = 20\,IR \text{ when } T_o = 290K$$

and where

I = noise diode current, in amperes

R = amplifier input resistance, in ohms

CHAPTER III: MIXER DIODES AND DETECTOR DIODES

Section 2: Mixer diodes used in communication applications

1 General

See section 1, clause 1.

2 Terminology and letter symbols

See section 1, clause 2.

3 Essential ratings and characteristics

3.1 General

The essential ratings and characteristics for each category of diode are marked with a + sign in the following table.

- Category A: discrete diode.
- Category B: diode element mounted on a substrate or integrated with a waveguide.

NOTE This includes those circuits which contain passive elements, such as d.c. bias supply circuits, d.c. protection circuits, directional couplers, filters. etc.; balanced types are also included. Circuits containing active elements, such as transistors, oscillator diodes, etc. are not included.

- Subcategory P: point contact diode.
- Subcategory S: Schottky barrier diode.

3.2 Ratings (limiting values)

The following ratings should be stated:

	Categories			
	A		B	
	P	S	P	S
3.2.1 Temperatures				
3.2.1.1 Range of operating temperatures	+	+	+	+
3.2.1.2 Range of storage temperatures	+	+	+	+
3.2.2 Current				
Maximum mean forward current under specified conditions at 25 °C		+		+
3.2.3 Power dissipation (including burn-out energy)				
3.2.3.1 Maximum c.w. power under specified conditions at 25 °C	+	+	+	+
3.2.3.2 Maximum burn-out energy by single pulse under specified conditions at 25 °C	+	+	+ (note 1)	+ (note 1)

	Categories			
	A		B	
	P	S	P	S
3.3 Electrical characteristics				
Unless otherwise specified, the following characteristics should be stated at 25 °C:				
3.3.1 Terminal capacitance				
Typical value under specified conditions	+	+		
3.3.2 Forward current				
Minimum value at specified voltage		+		
3.3.3 Reverse current				
Maximum value at specified reverse voltage		+		
3.3.4 Ratio of the forward current at two specified bias voltages, or coefficient *n* (note 2)				
Typical value		+		
3.3.5 Voltage standing wave ratio				
Maximum value when fitted on mount and operating under specified conditions (note 3)	+	+	+ (note 5)	+ (note 5)
Maximum value(s) under specified conditions (note 4)				
3.3.6 IF impedance				
Minimum and maximum values under specified conditions (note 3)	+	+	+ (note 5)	+ (note 5)
3.3.7 Conversion loss				
Typical value under specified conditions (note 3)	+	+	+ (note 5)	+ (note 5)
3.3.8 Overall noise factor				
Maximum value under specified conditions (notes 3 and 6)	+	+	+	+
3.3.9 Isolation				
The ratio of the value of the local oscillator signal measured at the local oscillator to the value measured at the input signal port				
Typical value, expressed in decibels, under specified conditions			+	+
3.4 Application data				
3.4.1 Recommended mean forward current, under specified operating conditions	+	+	+	+
3.4.2 Series inductance				
Typical value	+	+		
3.4.3 Output noise temperature ratio				
Typical value	+	+	+	+

NOTE 1 If the diode is integrated with the elements of the d.c. circuits such as bias supply circuit or bias protection circuit, the overall value shall include the effect of this d.c. circuit.

NOTE 2 "*n*" is defined by:

$$i = i_s \left(e^{\frac{qV}{nkT}} - 1\right)$$

where

i = diode forward current
i_s = reverse saturation current
q = electron charge
V = applied bias voltage
k = Boltzmann's constant
T = absolute temperature.

NOTE 3 The device holder shall be specified by the manufacturer.

NOTE 4 If input signal and local oscillator terminals are separated, the voltage standing wave ratio for each terminal should be given. In this case, the frequencies should be specified for each terminal.

NOTE 5 In addition, it is necessary to give the frequency response, typical value, in either numerical or graphical representation.

NOTE 6 The noise factor F_o shall be determined for an assumed or actual F_{if} of 1,5 dB.

4 Measurement methods

See 4.1 to 4.9, section 1.

CHAPTER III: MIXER DIODES AND DETECTOR DIODES

Section 3: Detector diodes

(Under consideration.)

CHAPTER IV: IMPATT DIODES

Section 1: Impatt diodes amplifiers

1 General

(To be defined.)

2 Terminology and letter symbols

2.1 Terms and letter symbols

2.1.1 Temperature

Storage temperature T_{stg}

Case operating temperature T_{case}

Resonant structure ambient operating temperature T_{amb}

Resonant structure body operating temperature T_{MB}

2.1.2 Voltage

Breakdown voltage $V_{(BR)}$

Operating voltage V_{OP}

2.1.3 Current

Reverse current I_R

Operating current I_{OP}

Continuous current I_A

Peak transient current I_{AM}

2.1.4 Power

Power dissipation P_D

Output power (for a defined oscillator structure) P_o

Added output power (for a defined amplifier structure) $P_{o\ add}$

Output power change with current $\Delta P_{o(\Delta I)}$,

Spurious output power P_{sp}

2.1.5 Capacitance and resistance

Case capacitance C_{case}

Junction capacitance C_j

Total capacitance C_{tot}

Junction-to-case thermal resistance $R_{th(j-c)}$

2.1.6 Frequency

Minimum frequency of mechanical tuning range f_{minM}

Maximum frequency of mechanical tuning range f_{maxM}

Minimum frequency of electrical tuning range f_{minE}

Maximum frequency of electrical tuning range f_{maxE}

Frequency change with current $\Delta f_{(\Delta I)}$

Frequency change at turn-on Δf_{on}

Change of frequency with temperature $\Delta f_{(\Delta T)}$

Change of output power with temperature $\Delta P_{\text{o}(\Delta T)}$

Change of frequency with load impedance (of an oscillator) $\Delta f_{(\Delta Z)}$

Change of output power with load impedance $\Delta P_{\text{o}(\Delta Z)}$

Injection locking range

The range of frequencies of an injected signal to which the oscillator will lock

Minimum injection locking frequency f_{minL}

Maximum injection locking frequency f_{maxL}

Oscillator conversion efficiency η, η_{OSC}

The ratio of RF power output to the d.c. input power

Power-added efficiency (for amplifiers or locked oscillators in an FM system) η, η_{add}

The ratio of the difference between the RF output power and the input power to the d.c. input power.

2.1.7 Other parameters

F.M. spot noise figure F_{fm}

Double sideband A.M. spot noise figure F_{am}

RF sum-on time t_{onRF}

2.2 Complementary definitions

2.2.1 Temperature

resonant-structure ambient operating temperature T_{amb}
the air temperature measured under operating conditions below the resonant structure in an environment of substantially uniform temperature, cooled only by natural air convection and not materially affected by reflective and radiant surfaces

resonant-structure body operating temperature T_{MB}
the temperature measured under operating conditions at a specified reference point on the body surface of the resonant structure

2.2.2 Voltage

operating voltage (of an Impatt diode) V_{OP}
the voltage across the terminals that results from the flow of operating current

2.2.3 Current

operating current (of an Impatt diode) I_{OP}
a current in the avalanche region at which the diode operates

2.2.4 Power

output power (for a defined amplifier structure) P_o
the power delivered to a matched termination at the output terminals of the oscillator structure

added output power (for a defined amplifier structure) $P_{o\ add}$
the power contributed by the amplifier structure to the output power (i.e. RF input power is excluded)

spurious output power P_{sp}
the total integrated output power excluding the power at the fundamental frequency

2.2.5 Capacitance

case capacitance C_{case}
the capacitance between the terminals of the diode case with no die installed

2.2.6 Frequency

frequency change at turn-on (for an oscillator) Δf_{on}
the frequency change from an initial value immediately following the application of power to the value finally reached

NOTE For specification purposes, it must be indicated how the initial value of frequency is defined.

2.2.7 Other parameters

F.M. spot noise figure F_{fm}

the ratio of:

1) the F.M. output noise power unit bandwidth (spectral density) at a single output frequency when the noise temperature of all input terminations is equal to the reference noise temperature T_0 at all frequencies that contribute to the output noise,

   to:

2) that part of item 1) caused by the noise of the signal-input termination at the signal-input frequency

NOTE 1 FM noise is that part of the total noise that is detected by a system that responds only to frequency modulation.

NOTE 2 The word "spot" has been introduced in the title to be consistent with 5.4.4, chapter IV, of IEC 60747-1.

double sideband AM spot noise figure F_{am}

the ratio of:

1) the AM output noise power per unit bandwidth (spectral density) at a single output frequency when the noise temperature of all input terminations is equal to the reference noise temperature T_o at all frequencies that contribute to the output noise,

   to:

2) that part of item 1) caused by the noise of the signal input termination at the signal input frequency

NOTE AM noise is that part of the total noise that is detected by a system that responds only to amplitude modulation.

RF turn-on time t_{onRF}

for a free-running oscillator, the time taken from switch-on to reach a specified frequency

For a locked oscillator or amplifier, the time taken from switch-on to reach a specified output power

3 Essential ratings and characteristics

3.1 General

The ratings of the electrical characteristics should be stated, either at ambient-rated temperature, or at case-related temperature.

3.2 Ratings (limiting values)

3.2.1 Temperature

3.2.1.1 Storage temperature

Minimum and maximum values.

3.2.1.2 Case operating temperature

Minimum and maximum values.

NOTE One of the temperatures given in 3.4.1 may be specified as an alternative.

3.2.2 Power dissipation

Maximum value at specified case temperature.

3.2.3 Continuous current

Maximum value in the avalanche region.

3.2.4 Peak transient current

Maximum value in the avalanche region, for specified pulse duration.

3.3 Characteristics

The following characteristics should be given at a case temperature of 25 °C:

3.3.1 Breakdown voltage

Minimum and maximum values, at specified reverse current.

3.3.2 Reverse current

Maximum value, at specified reverse voltage below the minimum breakdown voltage.

3.3.3 Total capacitance

Minimum and maximum values, under specified bias voltage conditions.

3.3.4 Junction-to-case thermal resistance

Maximum value.

3.4 Additional ratings and characteristics

When the diode is specified for use in a defined resonant structure, the following additional ratings and characteristics should be given:

3.4.1 Ratings (limiting values)

Either:

3.4.1.1 Resonant structure ambient operating temperature

Minimum and maximum values.

Or:

3.4.1.2 Resonant structure body operating temperature

Minimum and maximum values at a specified reference point.

3.4.2 Characteristics

The following characteristics of the avalanche diode and its defined resonant structure should be given at an ambient or structure body temperature of 25 °C unless otherwise stated:

3.4.2.1 Operating voltage

Maximum value, at specified operating current(s).

3.4.2.2 Output pouter (for a defined oscillator structure)

Minimum and, where appropriate, maximum values, at specified diode operating current(s) and, if applicable, over the specified mechanical or electrical tuning range and at a specified voltage standing wave ratio (v.s.w.r.).

3.4.2.3 Added output power (for a defined amplifier structure)

Minimum and, where appropriate, maximum values, at specified diode operating current(s) and, if applicable, over the specified mechanical or electrical tuning range and at a specified v.s.w.r.

The following characteristics should be given where applicable:

3.4.2.4 Tuning range (mechanical)

Minimum and maximum frequencies at specified operating current.

3.4.2.5 Tuning range (electrical)

Minimum and maximum frequencies over a specified tuning diode voltage range and at a specified operating current.

3.4.2.6 Frequency change with operating current

Minimum or maximum value over a specified operating current range.

3.4.2.7 Output power change with current

Maximum value over a specified operating current range.

3.4.2.8 F.M. noise figure

Maximum value under specified conditions, preferably selected from the following:

Bandwidth: 1 Hz, 10 Hz, 100 Hz or 1 kHz
and 10 kHz, 100 kHz, 1 MHz or 10 MHz for carrier.

3.4.2.9 Double sideband A.M. noise figure

Maximum value under specified conditions, preferably selected from those in 3.4.2.8.

3.4.2.10 Frequency change at turn-on

Maximum value under specified conditions.

3.4.2.11 Spurious output power(s)

Maximum value(s), at specified frequencies and under specified conditions.

3.4.2.12 Frequency change with temperature

Maximum value over the operating temperature range, under specified conditions.

3.4.2.13 Output power change with temperature

Maximum value over the operating temperature range, under specified conditions.

3.4.2.14 Frequency change with load impedance variation

Maximum value for a specified voltage standing wave ratio (v.s.w.r.), all phases.

3.4.2.15 Output power change with load impedance variation

Maximum value for a specified v.s.w.r., all phases.

3.4.2.16 RF turn-on time

Maximum value under specified conditions.

3.4.2.17 Injection locking range

Minimum and maximum injection locking frequencies at specified injection locking power.

3.4.2.18 Continuous (direct) to RF conversion efficiency (for oscillators)

Minimum value under specified conditions.

3.4.2.19 Power-added efficiency (for amplifiers)

Minimum value under specified conditions.

3.5 Supplementary information

3.5.1 Case capacitance

Typical value.

3.5.2 Junction capacitance

Typical value under specified conditions.

CHAPTER IV: IMPATT DIODES

Section 2: Impatt diodes oscillators

(Under consideration.)

CHAPTER V: GUNN DIODES

1 General

(Under consideration.)

2 Terminology and letter symbols

2.1 Pulse breakdown voltage (of a Gunn diode) $V_{(BR)}$

The lowest value of the voltage under specified pulse conditions at which the resistance of the diode decreases suddenly.

3 Essential ratings and characteristics

(Under consideration.)

4 Measurement methods

4.1 Pulse breakdown voltage $V_{(BR)}$

4.1.1 Purpose

To measure the threshold voltage of a Gunn diode under the specified conditions.

4.1.2 Circuit diagram

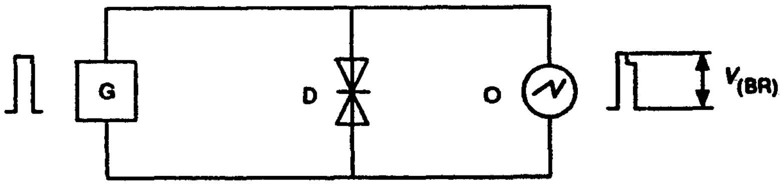


Figure 36

where $V_{(BR)}$ is the pulse breakdown voltage

4.1.3 Circuit description and requirements

D is the diode being measured

G is the nanosecond pulse generator

O is the oscilloscope

4.1.4 Measurement procedure

The input pulse is applied to the diode by the pulse generator, G.

Increase the amplitude of the input pulse until the back-porch of the pulse observed on the oscilloscope drops abruptly.

Immediately prior to this time the voltage across the diode is the threshold voltage of the Gunn diode.

4.1.5 Specified conditions

Ambient temperature

Pulse duration

Pulse duty factor

4.1.6 Precautions

The pulse duration and duty cycle shall be chosen to prevent the permanent change of characteristics or destruction of the device.

4.2 Threshold voltage

4.2.1 Purpose

To measure the threshold voltage of a Gunn diode under specified conditions.

4.2.2 Circuit diagram

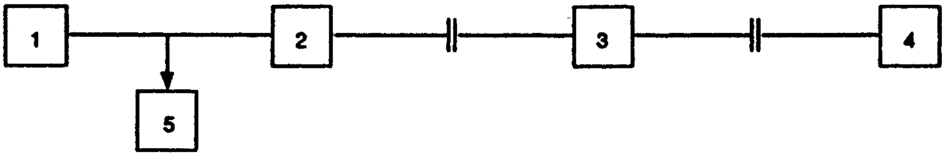


Figure 37

where

1 is the voltage generator

2 is the cavity with the diode being measured

3 is the variable attenuator

4 is the oscillation indicator (power meter or detector chamber with a microammeter or a stroboscopic oscilloscope)

5 is the d.c. voltage meter

4.2.3 Circuit description and requirements

For proper measurement it is necessary to have a cavity chamber, the design of which is specified for each type of diode.

The cavity chamber shall meet the following requirements:

- have adjustment elements enabling visual oscillation mode of a diode to be observed within the specified frequency band;
- ensure a specified microwave frequency coupling in the diode supply circuit;
- ensure the heat removal from the diode in the operating conditions. In this case the critical holding temperature should not exceed a specified maximum rating for a particular type of diode. The input resistance of the voltage source should not exceed 10 % of the diode resistance.

4.2.4 Measurement procedure

The diode is inserted into the cavity. The supply voltage is gradually increased until oscillation occurs. The moment when the oscillation occurs is defined by the indicator (4). The cavity is adjusted to the maximum indicator reading. When the indicator is overloaded, an attenuator is used. The supply voltage is reduced to zero. These operations are repeated until the minimum voltage value at which oscillation occurs is achieved. The threshold voltage value is read on the d.c. voltage meter at the moment when the oscillation occurs.

4.3 Resistance

4.3.1 Voltmeter-ammeter method

4.3.1.1 Purpose

To measure the resistance of a Gunn diode under specified conditions.

4.3.1.2 Circuit diagram

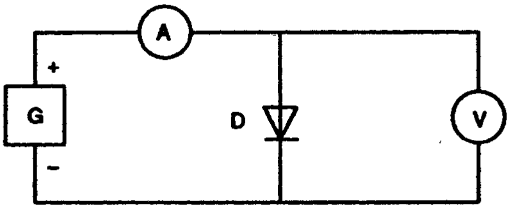


Figure 38

where

G is the d.c. generator

A is the d.c. ammeter

V is the d.c. voltmeter

D is the diode being measured

4.3.1.3 Circuit description and requirements

The input resistance of the voltmeter should be high with respect to the maximum resistance of the diode.

4.3.1.4 Measurement procedure

The measuring current shall be significantly lower than the threshold current, I_{TO}.

Take into account the voltage drop on wires and terminals connecting the diode to the measurement circuit.

For this purpose the voltage drop on the short-circuited terminals of the diode holder is measured.

The resistance of a Gunn diode is calculated by the formula:

$$R = \frac{U}{I}$$

where

R is the resistance of the diode being measured

U is the voltage drop on the diode being measured

I is the current through the diode being measured

4.3.2 Alternative method

4.3.2.1 Circuit diagram

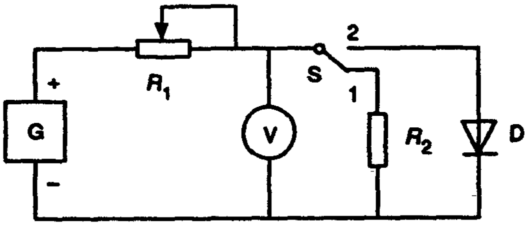


Figure 39

where

G is the d.c. generator

R_1 is the variable resistor

V is the d.c. voltmeter

S is the switch

R_2 is the calibrated resistor

D is the diode being measured

4.3.2.2 Circuit description and requirements

The internal resistance of the d.c. generator (G and R_1) should be high with respect to the maximum resistance of the diode. The value of the variable resistor, R_1, is chosen so that the current through the diode can be adjusted within ±10 %.

The resistance of the calibrated resistor, R_2, should not be less than the maximum rating of the diode resistance.

4.3.2.3 Measurement procedure

The switch S is set in position 1 and the meter scale is calibrated by the resistor, R_1.

Then the switch S is set in position 2 and the resistance value is read on the meter scale.

CHAPTER VI: BIPOLAR TRANSISTORS

(Under consideration.)

CHAPTER VII: FIELD EFFECT TRANSISTORS

1 General

(To be defined.)

2 Terminology and letter symbols

NOTE This chapter contains the main specific letter symbols used for GaAs FET in microwave applications. Letter symbols of parameters preceded by the asterisk * are already published in chapter II, IEC 60747-8.

2.1 Terms and letter symbols

2.1.1 Temperature

Channel temperature	T_j

2.1.2 Voltages

* Drain-source voltage	V_{DS}
* Gate-source voltage	V_{GS}
* Gate-source cut-off voltage	V_{GSoff}
* Gate-source breakdown voltage	$V_{(BR)GS}$

2.1.3 Current

* Drain current with gate short-circuited to source	I_{DSS}

2.1.4 Powers

Output power at 1 dB gain compression	$P_{o(1dB)}$
or:	
Output power at specified input power	P_o
Power gain at 1 dB gain compression	$G_{P(1dB)}$
Power added efficiency	η_{add}
Associated (power) gain	G_{as}
Maximum available gain (note 1)	$G_{a(max)}$
Minimum noise figure	F_{min}
Source reflection factor for minimum noise figure (notes 2 and 3)	r_{GFmin}
Equivalent input noise resistance	R_n

NOTE 1 The abbreviation "MAG" is still in common use for maximum available gain.

NOTE 2 For source reflection coefficient (factor), see 5.3.3, chapter II of IEC 60747-7[*].

NOTE 3 The symbol "Γ_{opt}" is still in common use for the source reflection factor for minimum noise figure.

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[*] IEC 60747-7 (all parts), *Semiconductor devices – Discrete devices – Part 7: Bipolar transistors*

2.1.5 Capacitance and resistance

Channel-case thermal resistance	$R_{th(j-c)}$

2.1.6 Frequency

Maximum frequency of oscillation	f_{max}

2.1.7 Other parameters

2.2 Complementary definitions

2.2.1 Temperature

2.2.2 Voltages

gate-source cut-off voltage V_{GSoff}
the gate-source voltage at which the magnitude of the drain current reaches a specified low value

gate-source breakdown voltage $V_{(BR)GS}$
the reverse voltage at which the gate current becomes greater than a specified value

2.2.3 Power

concept of power-gain compression

ratio of:

the magnitude of the power gain at a reference signal level

to

its magnitude at a specified higher signal level.

NOTE The power-gain compression is usually expressed in dB.

power-added efficiency η_{add}

the ratio of:

1) the difference between the output power and the input signal power

to

2) the d.c. input power

NOTE This ratio is normally expressed as a percentage.

associated gain G_{as}
power gain when the FET is matched (for example, by means of an external network)

Ratio of:

the difference between the output signal power and the input signal power

to

the input signal power

NOTE The gain is normally given under conditions matched for minimum noise. In this case the "associated gain for minimum noise" should be used.

The shorter term "associated gains" may be used if no ambiguity is likely to occur.

minimum noise figure
the minimum value of the noise figure that can be obtained through adjustment of the source impedance under specified bias condition and a specified frequency

equivalent input noise resistance
the quotient of the equivalent input noise voltage and the equivalent input noise current (see 5.4.9 and 5.4.10, chapter IV of IEC 60747-1[**]).

2.2.4 Capacitance and resistance

channel-to-case thermal resistance $R_{th(j-c)}$
quotient of:

1) the difference between the virtual temperature of the channel region and the temperature of the case, and
2) the steady-state power dissipation in the field-effect transistor

2.2.5 Other definitions

Schottky barrier
a junction between a metal and a semiconductor in which a transition region, formed within the semiconductor surface, acts as a rectifying barrier

metal-semiconductor field-effect transistor (MESFET)
a field-effect transistor having one or more gate regions that form Schottky barriers with the channel

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[**] IEC 60747-1:1983, *Semiconductor devices – Discrete devices – Part 1: General*

3 Essential ratings and characteristics

The essential ratings and characteristics for each category of GaAs FET used in microwave applications are marked in the table with a sign +:

Category A: power devices

Category B: low-noise devices.

	Categories	
	A	B
3.1 Ratings (limiting values)		
3.1.1 Drain-source voltage (V_{DS})		
Maximum value	+	+
3.1.2 Gate-source voltage (V_{GS})		
Maximum value	+	+
3.1.3 Storage temperature		
Minimum and maximum values	+	+
Either		
3.1.4 Channel temperature (T_j)		
Maximum value	+	+
Or		
3.1.5 Total power dissipation		
Maximum value over the specified range of operating ambient or reference-point temperatures. Any special requirements for ventilation and/or mounting shall be stated	+	+
3.2 Characteristics		
Characteristics are to be given at 25 °C except where otherwise stated. Other temperatures should be taken from the list in 3.4 of IEC 60147-0 or clause 5, chapter VI IEC 60747-1.		
3.2.1 DC characteristics		
3.2.1.1 Drain current with gate short-circuited to source (I_{DSS})		
Minimum and maximum values at specified drain-source voltage	+	+
3.2.1.2 Gate-source cut-off voltage (V_{GSoff})		
Minimum and maximum values at specified coin-source voltage and drain current	+	+
3.2.1.3 Gate-source breakdown voltage ($V_{(BR)GS}$)		
Minimum value at specified gate-source reverse current	+	+
3.2.1.4 Channel-case thermal resistance ($R_{th(j-c)}$)		
Maximum value (when channel temperature is specified in 3.1.4)	+	

	Categories	
	A	B
3.2.2 RF Characteristics		
3.2.2.1 Output power at a gain compression of 1 dB ($P_{o(1dB)}$)		
Minimum and typical values under specified conditions	+	
or:		
Output power at specified input power (P_o)		
Minimum and typical values under specified conditions		
3.2.2.2 Power gain at a gain compression of 1 dB ($G_{P(1dB)}$) (see note 1)		
Minimum and typical values under specified conditions	+	
3.2.2.3 Power-added efficiency (η_{add})		
Minimum and typical values under specified conditions	+	
3.2.2.4 Noise figure		
Typical and maximum values under specified conditions		+
3.2.2.5 Associated gain (G_{as})		
Minimum and typical values under specified conditions		+
3.2.2.6 Maximum frequency of oscillation (f_{max})		
Typical value under specified conditions		+
3.2.2.7 Maximum available gain ($G_{a(max)}$)		
Typical value under specified conditions		+
3.2.2.8 Minimum noise figure		
Maximum value under specified conditions		+
3.2.2.9 Source reflection factor for minimum noise figure		
Maximum and minimum values under specified conditions		+
NOTE Maximum and minimum values respectively should be prescribed for magnitude and angle.		
3.2.2.10 Equivalent input noise resistance		
Maximum and minimum values under specified conditions		+

NOTE Subclause 3.2.2.2 can be omitted if using output power at specified input power in 3.2.2.1.

4 Measurement methods

4.1 General

4.1.1 Polarity

The polarities of the power supplies, shown in the circuits in this standard, are applicable to N-Channel type devices. However, the circuits can be adapted for P-Channel type devices by changing the polarities of the meters and the power supplies.

4.1.2 General precautions

The general precautions listed in clause 2, chapter VII, of IEC 60747-1, apply. In addition, special care should be taken to use low-ripple d.c. supplies and to decouple adequately all bias supply voltages at the frequency of measurement.

4.1.3 Handling precautions

Because of the very high input resistance of field-effect transistors, the gate insulation layer (for insulated-gate types) or the gate junction (for junction-gate types) may be irreversibly damaged if an excessive voltage is allowed to build up, for example, due to contact with electrostatically charged persons, leakage currents from soldering irons, etc.

When handling these devices, the handling precautions given in clause 1, chapter IX, of IEC 60747-1, shall therefore be observed.

4.1.4 Type categories

(Under consideration.)

4.2 Drain current, with gate short-circuited to source (I_{DSS})

The measuring method given in clause 3, chapter IV, of IEC 60747-8, is applicable.

4.3 Gate-source cut-off voltage (V_{GSoff})

The measuring method given in clause 5, chapter IV, of IEC 60747-8, is applicable with the sentence in 5.3 being replaced by "See general precautions".

4.4 Gate-source breakdown voltage ($V_{(BR)GS}$)

4.4.1 Purpose

To measure the gate-source breakdown voltage of a field-effect transistor under specified conditions.

4.4.2 Circuit diagram

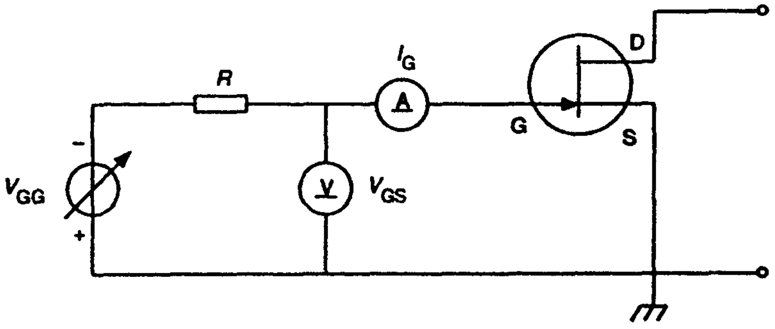


Figure 40 – Basic circuit for the measurement of gate-source breakdown voltage, $V_{(BR)GS}$

4.4.3 Circuit description and requirements

R is a protective resistor.

4.4.4 Measurement procedure

Increase progressively the value of the gate-source reverse voltage from zero until the first value of the specified value I_G or $V_{(BR)GSO}$ is reached. If the current value I_G is reached first, the transistor is faulty. If the specified voltage $V_{(BR)GSO}$ is reached first, the transistor is acceptable.

4.4.5 Specified conditions

Ambient or point temperature, T_{amb} or T_{case}

Gate current, I_G

Breakdown voltage, $V_{(BR)GSO}$

4.5 Thermal resistance, channel-to-case ($R_{th(ch-c)}$, $R_{th(j-c)}$)

4.5.1 Purpose

To measure the thermal resistance, channel-to-case of a field-effect transistor under specified conditions.

4.5.2 Circuit diagram

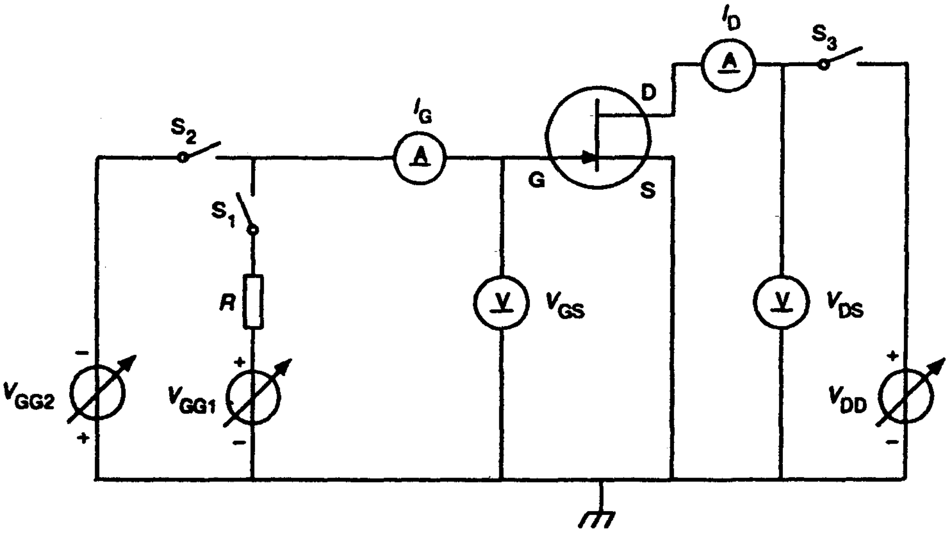


Figure 41 – Circuit for the measurement of thermal resistance, channel-to-case

4.5.3 Principle of measurement

The method uses the gate-source forward voltage, V_{GSF}, at open-circuit drain for a fixed reference gate forward current, $I_{G(ref)}$, as temperature-sensitive characteristic for the measurement of the (virtual) channel temperature, T_{ch}.

The method consists of two steps:

1) Establishing of the individual calibration curve, $V_{GSF} = f(T_{ch})$ which is then approximated by a straight line. During this calibration, T_{ch} is equivalent to T_{amb}.

   The slope of this line is the temperature coefficient, α, of the gate-source forward voltage:

$$\alpha = \frac{\Delta V_{GSF}}{\Delta T_{ch}} \qquad \text{(1) (see figure 43)}$$

2) Application of a constant power dissipation, $V_{DS} \times I_D$, until thermal equilibrium is reached, and measurement of the resulting change (ΔV_{GSF}) of the gate-source forward voltage.

   The thermal resistance is then calculated as:

$$R_{th(ch-c)} = \frac{\Delta V_{GSF}}{\alpha} \cdot \frac{1}{V_{DS} \cdot I_D} \qquad (2)$$

4.5.4 Circuit description and requirements

Resistor *R* must be high enough, compared with the static gate-source input resistance, to ensure sufficient constancy of the reference gate forward current.

V_{GG1} and *R* may be replaced by a constant current source.

The timing of the d.c. pulses supplied to the device being measured is shown in figure 42. The current passing through the voltmeter for V_{GS} must be negligible compared with the forward gate current of the device being measured.

4.5.5 Precautions to be observed

See general precautions.

The specified case temperature of the device being measured shall be kept constant during the measurement.

4.5.6 Measurement procedure

The measurement consists of two parts, the measurement of the thermal coefficient and the measurement of thermal resistance, channel-to-case.

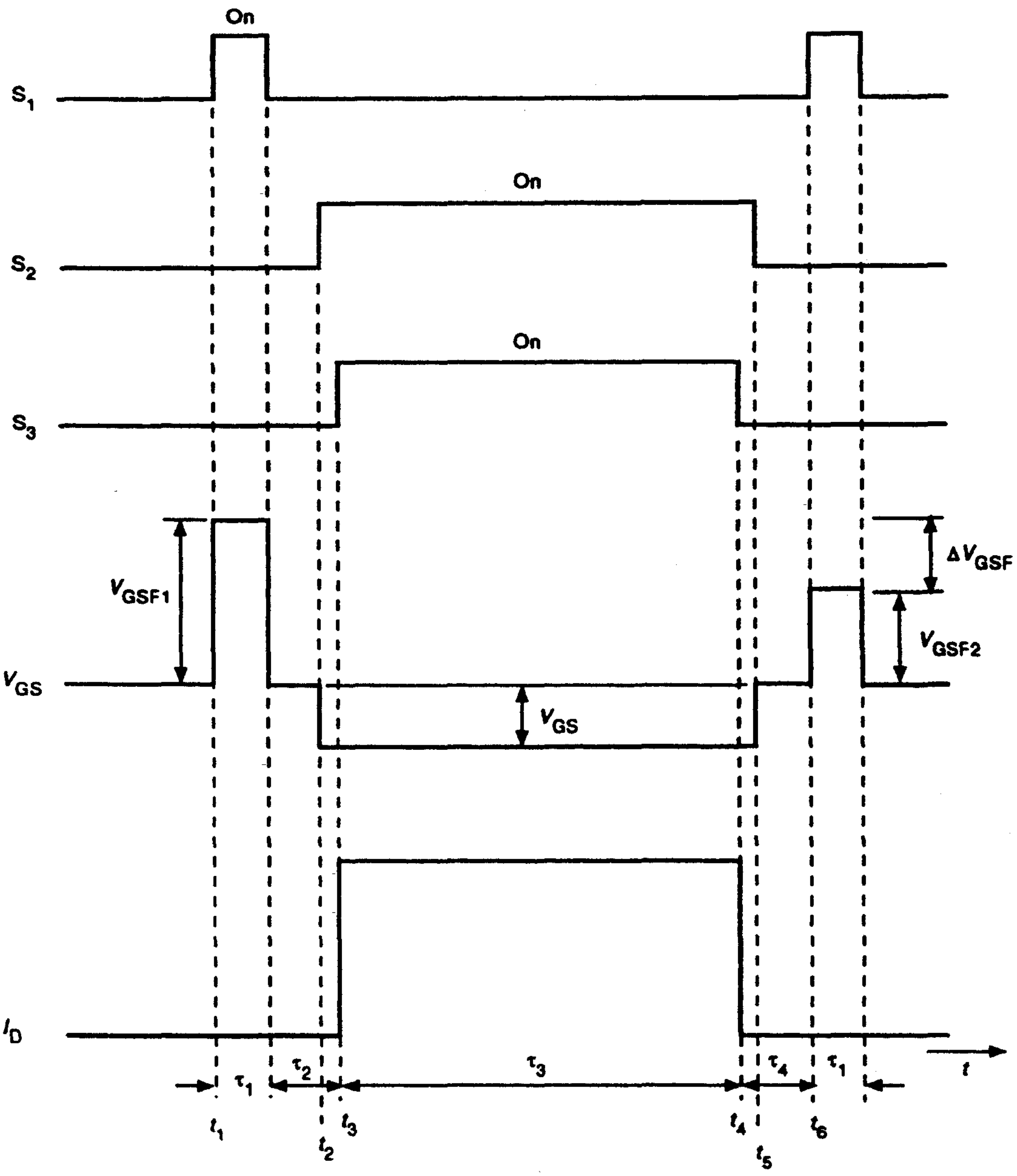


Figure 42 – Timing chart of d.c. pulse to be supplied to the device being measured

4.5.6.1 Measurement of α

The device being measured is mounted on a heating block (or placed in a heating oven) and connected to the circuit as shown in figure 41. Switches S_2 and S_3 are off, switch S_1 is on.

R is adjusted such that the reference gate forward current, $I_{G(ref)}$, has a suitable value for the purpose of the measurements.

This value is not changed again during the whole measurement procedure for α and $R_{th(ch-c)}$. After this adjustment, switch S_1 is opened.

This calibration curve, $V_{GSF} = f(T_{ch})$, is established by measuring a sufficient number of points of the curve to allow for a sufficiently precise straight-line approximation. For this, in each point of the curve, the temperature of the heating block is set to a measured value, T_{ch}.

After thermal equilibrium is reached, switch S_1 is closed for the same time τ_1 as it will later be closed for at the measurement $R_{th(ch-c)}$. The gate-source forward voltage is recorded.

From the measured points the straight-line approximation is derived, and α is calculated from its slope (see figure 43).

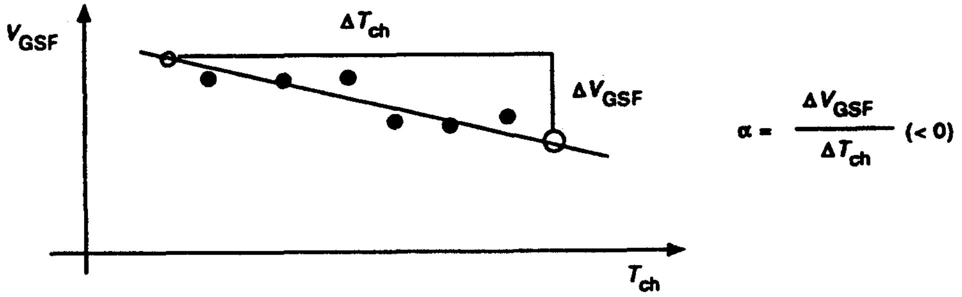


Figure 43 – Calibration curve $V_{GSF} = f(T_{ch})$ for fixed $I_{G(ref)}$, evaluation of α

4.5.6.2 Measurement of $R_{th(ch-c)}$

The device being measured is connected to the circuit as shown in figure 41. The measurement begins after thermal equilibrium is reached. At $t = t_1$, S_1 is switched on for the period τ_1 and the gate-source forward voltage V_{GSF1} is recorded. After τ_1, S_1 is switched off.

Period τ_1 is usually selected to be several tens of microseconds.

At $t = t_2$, S_2 is switched on. At $t = t_3$, S_3 is switched on, and V_{GG2} is adjusted to reach the required value of I_D. V_{DS} and I_D are recorded.

After the period τ_3, when thermal equilibrium is reached, S_3 is switched off at $t = t_4$. Usually, several hundreds of milliseconds for τ_3 will be sufficient. S_2 is switched off at $t = t_5$, just after S_3 is switched off. At $t = t_6$, after the delay time τ_4 has elapsed with respect to delay time τ_4, S_1 is switched on again for the period τ_1 and the gate-source forward voltage, V_{GSF2}, is recorded.

The above-described measurement procedure is repeated for increasing values of τ_4, all other conditions being held constant. The resulting values for V_{GF2} are recorded.

These values are inserted in a graph showing $V_{GSF2} = f(\tau_4)$ (see figure 44). From the graph, V_{GSF2^*} can be extrapolated, which is V_{GSF2} for $\tau_4 = 0$. $R_{th(ch-c)}$ is calculated as:

$$R_{th(ch-c)} = \frac{V_{GSF2^*} - V_{GSF1}}{\alpha} \cdot \frac{1}{V_{DS} \cdot I_D} \qquad (3)$$

Note that both$(V_{GSF2^*} - V_{GSF1})$ and α have a negative value.

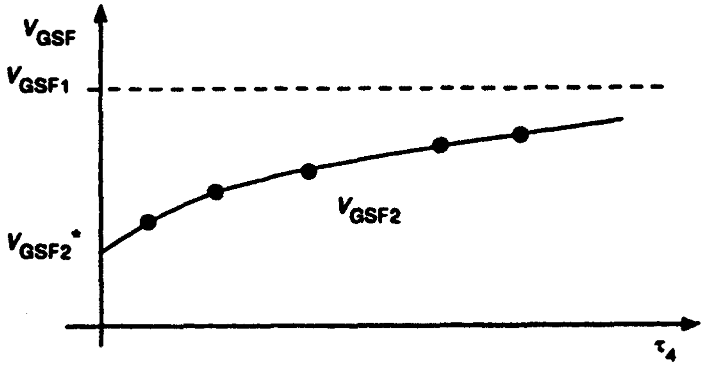


Figure 44 – V_{GSF2} in function of delay time τ_4

4.5.7 Specified conditions

Ambient temperature:	T_{amb}
Case temperature:	T_{case}
Reference gate-source forward current:	I_G
Drain current:	I_D
Drain source voltage:	V_{DS}

4.6 Output power at 1 dB-gain compression ($P_{o(1dB)}$)

4.6.1 Purpose

To measure the output power at 1 dB-gain compression of a field-effect transistor under specified conditions.

4.6.2 Circuit diagram

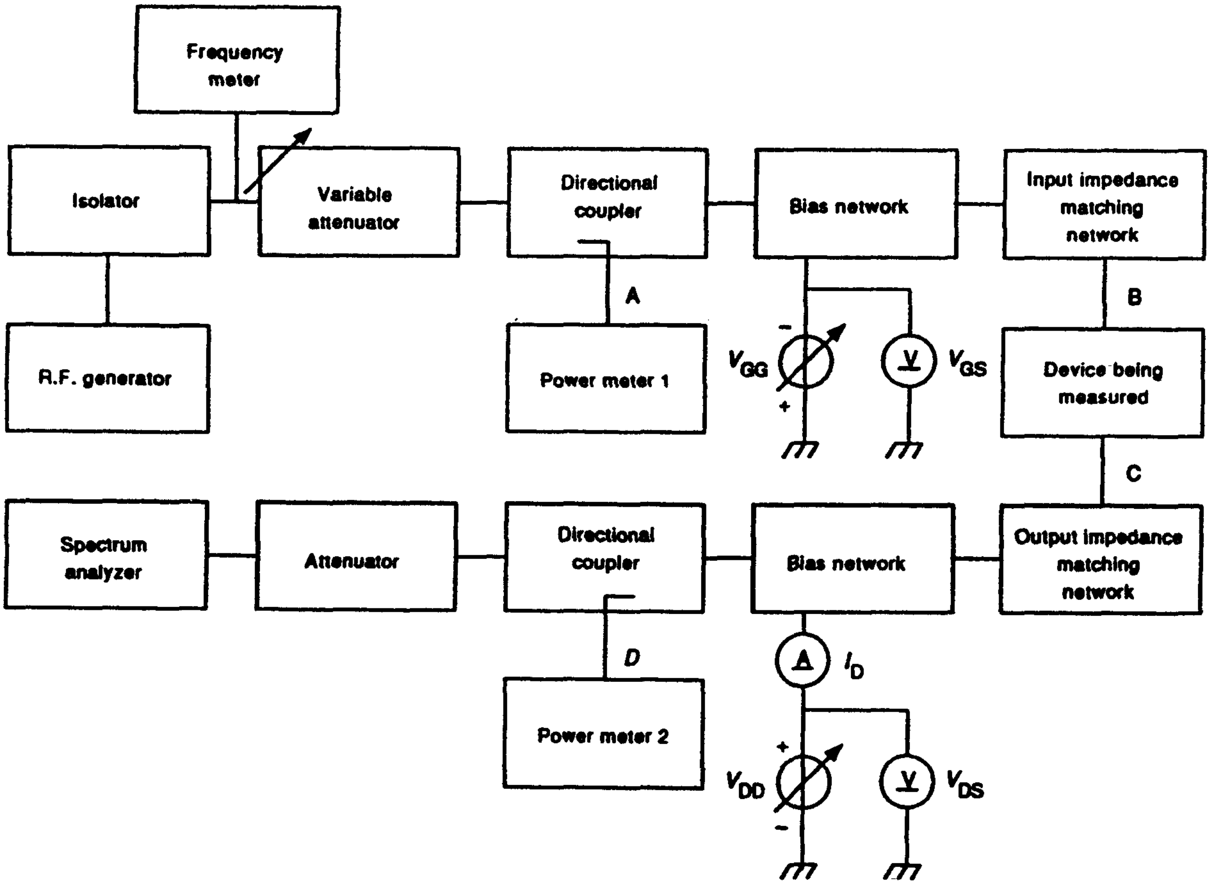


Figure 45 – Circuit for the measurement of output power at 1 dB-gain compression

4.6.3 Principle of measurement

In the circuit diagram shown in figure 45, the input power, P_i, and the output power, P_o, of the device being measured are derived from the following equations:

$$P_i = P_1 - L_1 \tag{4}$$

$$P_o = P_2 - L_2 \tag{5}$$

where P_1 and P_2 are the values indicated by the power meters 1 and 2, respectively. L_1 and L_2 are the circuit losses from point A to point B and from point C to point D shown in figure 45, respectively. P_i, P_o, P_1 and P_2 are expressed in dBm. L_1 and L_2 are expressed in dB.

Power gain G_p in dB is derived from equations (4) and (5) as follows:

$$G_p = P_o - P_i \tag{6}$$

The output power at 1 dB-gain compression, $P_{o(1dB)}$, is the value where the gain decreases by 1 dB, compared with the linear gain.

4.6.4 Circuit description and requirements

The purpose of the isolator is to enable the power level to the device being measured to be kept constant irrespective of impedance mismatches at its input. The device being measured should be mounted on the test fixture having a good heat flow. The circuit losses L_1 and L_2 should be measured beforehand.

NOTE It is desirable in the measurement of L_1 and L_2 that the input and output-impedance network are tuned beforehand.

4.6.5 Precautions to be observed

There should not be any abrupt impedance change at the input and output matching circuits. Oscillation, which is checked by a spectrum analyzer, shall be eliminated during these measurements. Termination must be capable of handling power supply.

4.6.6 Measurement procedure

The frequency of the RF generator should be adjusted to the specified value.

The gate-source voltage, V_{GS}, near gate-source cut-off voltage is applied.

The specified drain-source voltage, V_{DS}, is applied.

The drain current is adjusted to the specified value by varying V_{GS}.

An input power just below the specified value P_{Imatch} is applied to the device being measured.

The input and output impedance matching networks are adjusted so that the power meter 2 shows the maximum value.

The input power is increased to the specified value P_{Imatch} and final adjustments are made to the impedance matching networks.

The value of the input power level is decreased by 15 dB down to the power level at which the power gain, G_p, is the linear gain, G_{lin} × G_{lin} is the gain measured in the region where the change of the output power in dBm is the same as that of the input power.

The input power is increased until the power gain is decreased by 1 dB, compared with linear gain, G_{lin}.

The output power is measured at 1 dB-gain compression point.

4.6.7 Specified conditions

Ambient or case-point temperature, T_{amb} or T_{case}

Drain-source voltage, V_{DS}

Drain current, I_D

Frequency

Input power, P_{Imatch}

4.7 Output power at specified input power (P_o)

4.7.1 Purpose

To measure the output power at specified input power of a field-effect transistor under specified conditions.

4.7.2 Circuit diagram

See the block diagram shown in figure 45.

4.7.3 Principle of measurements

Output power, P_o, at specified input power is derived from the equation (5).

4.7.4 Circuit description and requirements

See the circuit description and requirements of 4.6.4.

4.7.5 Precautions to be observed

See the precautions of 4.6.5.

4.7.6 Measurement procedure

The frequency of the RF generator is adjusted to the specified value.

The gate-source voltage, V_{GS}, near gate-source cut-off voltage is applied.

The specified drain-source voltage, V_{DS}, is applied.

The drain current is adjusted to the specified value by varying V_{GS}.

An input power just below the specified value is applied to the device being measured.

The input and output impedance matching networks are adjusted so that the power meter 2 shows the maximum value.

The input power is increased to the specified value and final adjustments are made to the impedance matching networks.

The output power is measured at the specified input power.

4.7.7 Specified conditions

Ambient or case-point temperature, T_{amb} or T_{case}
Drain-source voltage
Drain current
Frequency
Input power

4.8 Power gain at 1 dB-gain compression $G_{P(1dB)}$

4.8.1 Purpose

To measure the power gain at 1 dB-gain compression of a field-effect transistor under specified conditions.

4.8.2 Circuit diagram

See the block diagram shown in figure 45.

4.8.3 Principle of measurements

Power gain is derived from the equation (6). Power gain at 1 dB-gain compression, $G_{P(1dB)}$, can be calculated by:

$$G_{P(1dB)} = G_{lin} - 1 \tag{7}$$

4.8.4 Circuit description and requirements

See the circuit description and requirements of 4.6.4.

4.8.5 Precautions to be observed

See the precautions of 4.6.5.

4.8.6 Measurement procedure

See the measurement procedure of 4.6.6. See the principle of measurements of 4.8.3.

4.8.7 Specified conditions

Ambient or point temperature, T_{amb} or T_{case}
Drain-source voltage
Drain current
Frequency
Input P_{Imatch}

4.9 Power added efficiency (η_{add})

4.9.1 Purpose

To measure the power added efficiency of a field-effect transistor under specified conditions.

4.9.2 Circuit diagram

See the block diagram shown in figure 45.

4.9.3 Principle of measurements

Power added efficiency (η_{add}) in per cent is given by:

$$\eta_{add} = \frac{P_o - P_i}{V_{DS} \cdot I_D} \times 100 \qquad (8)$$

where

V_{DS} is the drain-source voltage in volts

I_D is the drain current in amperes

P_o and P_i are expressed in watts

4.9.4 Circuit description and requirements

See the circuit description and requirements of 4.6.4.

4.9.5 Precautions to be observed

See the precautions of 4.6.5.

4.9.6 Measurement procedure

The frequency of the RF generator should be adjusted to the specified value.

The gate-source voltage, V_{GS}, near gate-source cut-off voltage is applied.

The specified drain-source voltage, V_{DS}, is applied.

The drain current is adjusted to the specified value by varying V_{GS}.

The specified input power is applied to the device being measured and input and output impedance matching networks are adjusted so that the power meter 2 shows the maximum value.

The output power, P_o, is measured at the specified input power, P_i.

The corresponding drain-source voltage, V_{DS}, and drain current, I_D, are also measured.

4.9.7 Specified conditions

Ambient or case temperature, T_{amb} or T_{case}

Drain-source voltage, V_{DS}

Drain-current, I_D

Frequency

Input power, P_i

4.10 Noise figure (F) and associated gain (G_{as})

4.10.1 Purpose

To measure the noise figure of a microwave field-effect transistor under specified conditions.

4.10.2 Circuit diagram

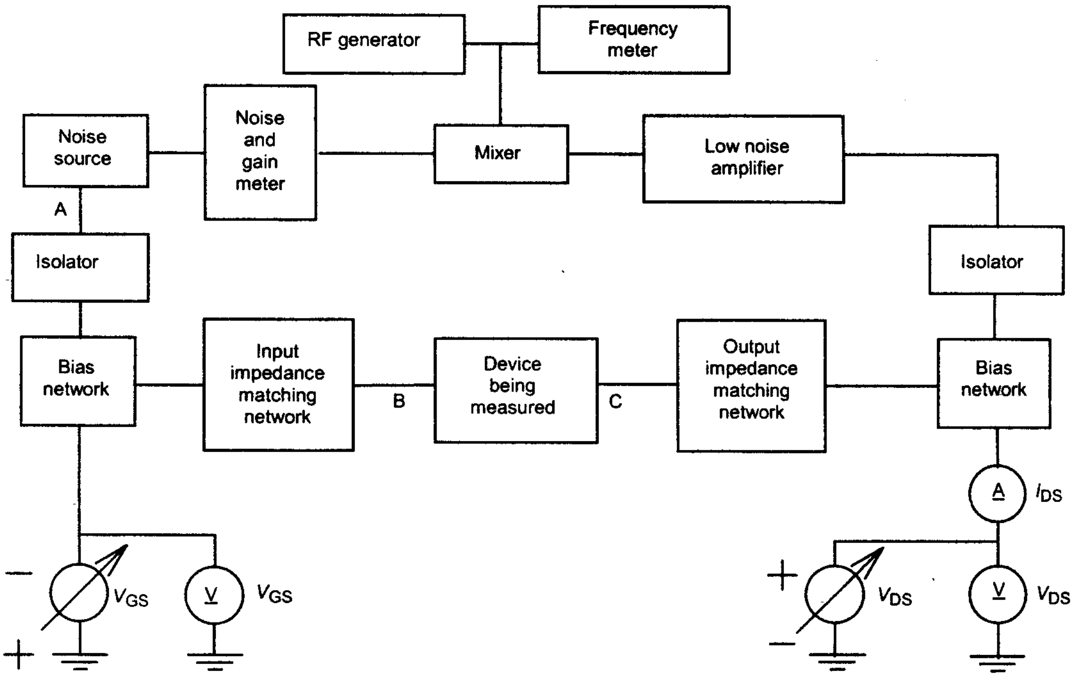


Figure 46 – Basic circuit for the measurement of the noise figure

4.10.3 Principle of measurement

The noise figure F of the device being measured is derived from the following equation:

$$F = 10\log\left(10^{(F_{12} - L_1)/10} - \frac{10^{F_2/10} - 1}{10^{G_m/10}}\right) \qquad (1)$$

where

F_{12} is the overall noise figure;

L_1 is the circuit loss from point A to B;

F_2 is the noise figure after point C at the output stage, and

G_{as} is the associated gain of the device being measured.

F, F_{12}, F_2, L_1 and G_{as} are expressed in decibels. The noise figure measurement is carried out by using the hot and cold measurement method. F_{12}, F_2 and G_{as} are calculated as follows:

$$F_{12} = 10\log\left(\frac{10^{ENR/10}}{(P_{N1}/P_{N2})-1}\right) \tag{2}$$

$$F_2 = 10\log\left(\frac{10^{ENR/10}}{(P_{N3}/P_{N4})-1}\right) \tag{3}$$

$$G_{as} = 10\log\left(\frac{P_{N1}-P_{N2}}{P_{N3}-P_{N4}}\right) \tag{4}$$

where

ENR	is the excess noise ratio of the noise source;
P_{N1} and P_{N2} in W	are the measured noise power under the hot and cold state of the noise source, respectively;
P_{N3} and P_{N4} in W	are the measured noise powers under the hot and cold state of the noise source, respectively, in the case of directly connecting point B to C in figure 46.

The temperature of the measurement is 290 K.

4.10.4 Circuit description and requirements

The circuit loss L_1 from point A to B should be measured beforehand.

4.10.5 Precautions to be observed

The entire circuit shall be shielded and grounded to prevent undesired signals. For noise figure measurement under the single-side-band (SSB) condition, careful attention shall be paid to the image and other spurious responses which are generated by the mixer. These spurious responses should be reduced so as to be negligible.

4.10.6 Measurement procedure

The frequency of the RF generator is adjusted to the specified condition.

In order to measure the noise contribution of the measurement system, connect point B to C in figure 46 without the device being measured and set the input and output impedance matching networks to 50 Ω.

The noise power P_{N3} and P_{N4} corresponding to the noise source hot and cold, respectively, are measured.

The noise figure F_2 in decibels is calculated by equation (3).

The device being measured is inserted as shown in figure 46.

The gate-source voltage V_{GS} (near the gate-source cut-off voltage) is applied.

The specified drain-source voltage V_{DS} is applied.

The drain current I_{DS} is adjusted to the specified value by varying V_{GS}.

During the adjustment of the input and output matching networks, the noise power P_{N1} and P_{N2} corresponding to the noise source hot and cold, respectively, are measured.

The noise figure F_{12} in decibels is calculated by equation (2).

The associated gain G_{as} in decibels is calculated by equation (4).

The noise figure F in decibels is calculated by equation (1).

The input impedance matching network is adjusted to the minimum value of F.

The output impedance matching network is adjusted to the maximum value of G_{as}.

Repeat the above two steps until no further reduction in noise figure F is possible.

4.10.7 Specified conditions

Ambient or reference point temperature

Drain source voltage

Drain current

Frequency

Single-side band or double-side band.

4.11 Maximum frequency of oscillation (f_{max})

4.11.1 Purpose

To measure the maximum frequency of oscillation of a field-effect transistor under specified conditions.

4.11.2 Circuit diagram

See the block diagram of the circuit for the S-parameter measurement which is shown in 13.6, chapter IV, of IEC 60747-7.

4.11.3 Circuit description and requirements

See the circuit description and requirements which are shown in 13.6, chapter IV, of IEC 60747-7.

4.11.4 Precautions to be observed

See the precautions to be observed which are shown in 13.6, chapter IV, of IEC 60747-7.

4.11.5 Measurement procedure

See the measurement procedure for the S-parameters S_{11}, S_{12}, S_{21}, S_{22} which is shown in 13.6, chapter IV, of IEC 60747-7.

All four S-parameters are measured for a frequency f_1, and the unilateral gain G_{u1} at the frequency f_1, is calculated as:

$$G_{u1} = 10\log\frac{\left|S_{21}-S_{12}\right|^2}{1+\left|S_{11}S_{22}-S_{21}S_{12}\right|^2-\left|S_{11}\right|^2-\left|S_{22}\right|^2-\left(S_{21}S_{12^*}+S_{21^*}S_{12}\right)} \qquad (11)$$

All four S-parameters are measured for a frequency f_2, and the unilateral gain G_{u2}, is calculated by the same formula as above. The maximum frequency of oscillation is calculated as:

$$\left(\frac{1}{G_{u1}-G_{u2}}\right)$$

$$f_{max} = \left(\frac{f_2^{\ G_{u1}}}{f_1^{\ G_{u2}}}\right) \tag{12}$$

4.11.6 Specified conditions

Ambient or case temperature, T_{amb} or T_{case}

Drain-source voltage, V_{DS}

Drain current or gate-source voltage, I_D or V_{GS}

Frequencies, f_1 and f_2

Input and output reference planes

Characteristic impedance

4.12 Maximum available gain ($G_{a(max)}$)

4.12.1 Purpose

To measure the maximum available gain of a field-effect transistor under specified conditions.

4.12.2 Circuit diagram

See the block diagram of the circuit in 13.6, chapter IV, of IEC 60747-7.

4.12.3 Measurement procedure

All four S-parameters are measured for a specified frequency as described in 4.12.5.

The maximum available gain is calculated using the following equations:

$$G_{a(max)} = |S_{21} / S_{12}| \bullet \left(K + \sqrt{K^2 - 1}\right) \left\{\begin{matrix} \text{for} & B_1 / 2 | C_1 | < -1 \\ \text{and} & B_2 / 2 | C_2 | < -1 \end{matrix}\right\} \tag{13}$$

$$G_{a(max)} = |S_{21} / S_{12}| \bullet \left(K - \sqrt{K^2 - 1}\right) \left\{\begin{matrix} \text{for} & B_1 / 2 | C_1 | > 1 \\ \text{and} & B_2 / 2 | C_2 | > 1 \end{matrix}\right\} \tag{14}$$

where K is a stability factor which is given by:

$$K = \frac{1 + |S_{11}\, S_{22} - S_{12}\, S_{21}|^2 - |S_{11}|^2 - |S_{22}|^2}{2|S_{21}\, S_{12}|} \tag{15}$$

and B_1, B_2, C_1 and C_2 are given by the following equations:

$$B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |S_{11}\,S_{22} - S_{12}\,S_{21}|^2 \tag{16}$$

$$B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |S_{11}\,S_{22} - S_{12}\,S_{21}|^2 \tag{17}$$

$$C_1 = S_{11} - S^*{}_{22}\,(S_{11}\,S_{22} - S_{12}\,S_{21}) \tag{18}$$

$$C_2 = S_{22} - S^*{}_{11}\,(S_{11}\,S_{22} - S_{12}\,S_{21}) \tag{19}$$

4.12.4 Specified conditions

Ambient or case temperature, T_{amb} or T_{case}

Drain-source voltage, V_{DS}

Drain-current or gate-source voltage, I_{D} or V_{GS}

Frequencies, f_1 and f_2

Input and output reference planes

Characteristic impedance

4.13 Minimum noise figure (F_{min}), equivalent input noise resistance (R_{n}) and source reflection factor for minimum noise figure (r_{GFmin})

4.13.1 Purpose

To measure the minimum noise figure, equivalent input noise resistance and source reflection factor for the minimum noise figure of a microwave field-effect transistor under specified conditions.

4.13.2 Circuit diagram

See the circuit diagram in 4.10.2.

4.13.3 Principle of measurement

See the principle of measurement in 4.10.3.

The noise figure dependence on the source admittance can be expressed as:

$$F = F_{\text{min}} + \frac{R_{\text{n}}}{G_{\text{s}}}\left\{(G_{\text{s}} - G_0)^2 + (B_{\text{s}} - B_0)^2\right\} \tag{1}$$

where

F	is the noise figure
F_{min}	is the minimum noise figure
R_{n}	is the equivalent input noise resistance
G_{s}	is the source conductance
B_{s}	is the source susceptance
G_0	is the source conductance for F_{min}
B_0	is the source susceptance for F_{min}

To determine the four parameters, F_{min}, R_{n}, G_0 and B_0, four dimensional simultaneous equations should be solved.

From equation (1)

$$F = F_{\text{min}} + \frac{R_{\text{n}}|Y_0|^2}{G_{\text{s}}} - 2R_{\text{n}}G_0 + \frac{R_{\text{n}}|Y_{\text{s}}|^2}{G_{\text{s}}} - 2R_{\text{n}}B_0\left(\frac{B_{\text{s}}}{G_{\text{s}}}\right) \tag{2}$$

where

$$Y_0 = G_0 + \text{j}B_0 \tag{3}$$

$$Y_{\text{s}} = G_{\text{s}} + \text{j}B_{\text{s}} \tag{4}$$

In equation (2), X_1, X_2, X_3 and X_4 are defined as

$$\begin{aligned} X_1 &= F_{\text{min}} - 2R_{\text{n}}G_0 \\ X_2 &= R_{\text{n}}|Y_0|^2 \\ X_3 &= R_{\text{n}} \\ X_4 &= R_{\text{n}}B_0 \end{aligned} \tag{5}$$

Then, equation (2) leads to the following equations for n different Y_{s}

$$\begin{gathered} F_{(1)} = X_1 + \frac{1}{G_{\text{s}(1)}}X_2 + \frac{|Y_{\text{s}(1)}|^2}{G_{\text{s}(1)}}X_3 - 2\left(\frac{B_{\text{s}(1)}}{G_{\text{s}(1)}}\right)X_4 \\ \bullet \\ \bullet \\ \bullet \\ F_{(n)} = X_1 + \frac{1}{G_{\text{s}(n)}}X_2 + \frac{|Y_{\text{s}(n)}|^2}{G_{\text{s}(n)}}X_3 - 2\left(\frac{B_{\text{s}(n)}}{G_{\text{s}(n)}}\right)X_4 \end{gathered} \tag{6}$$

Substituting X_1, X_2, X_3 and X_4 obtained from equation (6) into equation (5), the four parameters are determined as follows:

$$F_{\text{min}} = X_1 + 2\sqrt{X_2X_3 - X_4{}^2} \tag{7}$$

$$R_{\text{n}} = X_3 \tag{8}$$

$$G_0 = \sqrt{X_2/X_3 - (X_4/X_3)^2} \tag{9}$$

$$B_0 = X_4/X_3 \tag{10}$$

Γ_{Fmin}, source reflection factor for F_{min}, is determined from the above G_0 and B_0.

4.13.4 Circuit description and requirements

See the circuit description and requirements in 4.10.4.

4.13.5 Precautions to be observed

See the precaution to be observed in 4.10.5.

4.13.6 Measurement procedure

The frequency of the RF generator is adjusted to the specified condition.

The device being measured is inserted as shown in figure 46.

The gate-source voltage V_{GS} (near gate-source cut-off voltage) is applied.

The specified drain-source voltage V_{DS} is applied.

The drain current I_{DS} is adjusted to the specified value by varying V_{GS}.

The input impedance matching network is adjusted so that the source admittance becomes $(G_{s(1)}, B_{s(1)})$.

The output impedance matching network is adjusted so that the maximum power gain is achieved.

The noise figure $F_{(1)}$ is measured in accordance with the procedure described in 4.10.6.

Repeating the above procedure n times, $F_{(1)-(n)}$ are determined for the n source admittance $(G_{s(1)-(n)}, B_{s(1)-(n)})$.

The noise parameters: F_{min}, R_n and Γ_{Fmin} are determined from the equations (6) to (10).

4.13.7 Specified conditions

- Ambient or reference point temperature
- Drain source voltage
- Drain current
- Frequency
- Single-side band or double-side band.

CHAPTER VIII: ASSESSMENT AND RELIABILITY – SPECIFIC REQUIREMENTS

1 Electrical test conditions

Test conditions and test circuits, for each device category, are listed in table 2. The relevant specification will state which test(s) will apply.

2 Failure criteria and failure-defining characteristics for acceptance tests

Failure-defining characteristics, their failure criteria and measurement conditions for each device category are listed in table 1.

NOTE Characteristics shall be measured in the sequence in which they are listed in this table because the changes of characteristics caused by some failure mechanisms may be wholly or partially masked by the influence of other measurements.

3 Failure criteria and failure-defining characteristics for reliability tests

(Under consideration.)

4 Procedure in case of a testing error

When a device has failed as a result of a testing error (such as a test equipment fault or measurement equipment fault, or an operator error), the failure shall be noted in the data record with an explanation of the cause.

Table 1

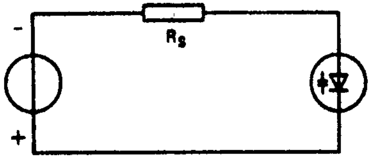
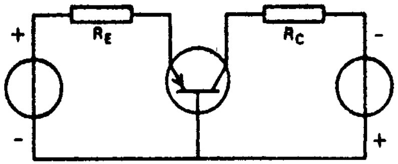
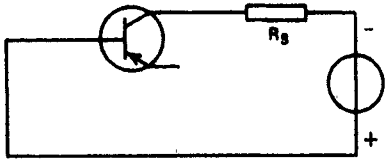
Device categories	Failure-defining characteristics	Failure criteria (note 1)	Measurement conditions
Variable capacitance diodes for tuning applications	I_R	>2 × USL	Highest V_R specified for I_R
	V_F	>1,1 × USL	Highest I_F specified for V_F
	Q or r_s	<0,5 × LSL >2 × USL	Lowest V_R specified for Q
Mixer diodes	(Under consideration)		
Impatt diodes	(Under consideration)		
Gunn diodes	(Under consideration)		
Bipolar transistors	I_{CBO}	>2 × USL	Highest V_{CB} specified for I_{CBO}
	h_{21E} (h_{21e} (note 2)	<0,8 × LSL >1,2 × USL	A value of I_c for which a h_{21E} (h_{21e}) tolerance (lower *and* upper limits) is specified
	V_{CEsat}	>1,2 × USL	Highest I_c specified for V_{CEsat}
	F (note 3)	>USL + 3 dB	Lowest I_c specified for F
Field-effect transistors	(Under consideration)		

NOTE 1 USL = upper specification limit.
LSL = lower specification limit.
IVD = initial value of individual device.

NOTE 2 Only where no h_{21E} tolerances are specified or where h_{21E} is unspecified.

NOTE 3 Where applicable.

Table 2

Device categories	Tests	Operating conditions			Test circuits	Remarks
		Current	Voltage	Temperature		
Variable capacitance diodes for tuning application	High temperature reverse bias		$V_R = V_R$ max.	Highest operating temperature $t_{amb(max)}$ or $t_{case(max)}$ as specified		R_s = current limiting resistor
Mixer diodes	Under consideration					
Impatt diodes	Under consideration					
Gunn diodes	Under consideration					
Bipolar transistors	Operating life	$I_C = \frac{P_{tot}\text{ max.}}{V_{CE}}$ (See 2.1.5 of chapter VIII, of IEC 60747-1)	$V_{CE} = 0{,}7\ V_{CEO}$ max. (note 1)	(See 2.1.3 of chapter VIII of IEC 60747-1)	 (note 2)	$R_E \geq \frac{10\ V_{EB}}{I_E}$ $R_C \approx \frac{V_{CB}}{I_C}$
	High temperature reverse bias		$V_{CB} = V_{CBO}$ max.	Highest operating temperature $t_{amb(max)}$ or $t_{case(max)}$ as specified	 (note 2)	R_s = current limiting resistor
Field effect transistors	Under consideration					

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Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110 002
Telephones : 2323 0131, 2323 33 75, 2323 9402

Telegrams : Manaksanstha
(Common to all offices)

Regional Offices :		Telephone
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Eastern	: 1/14 C.I.T. Scheme VII M, V. I. P. Road, Kankurgachi KOLKATA 700 054	2337 8499, 2337 8561 2337 8626, 2337 9120
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